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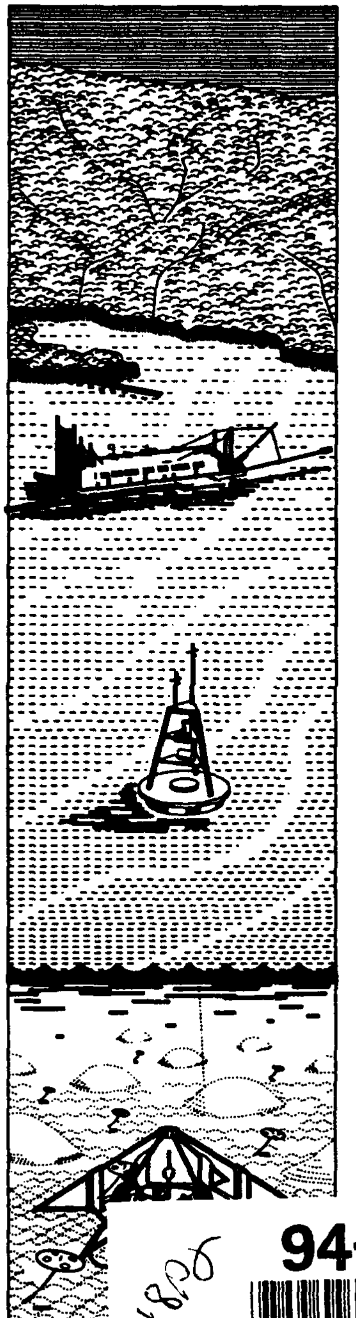

DREDGING RESEARCH PROGRAM

TECHNICAL REPORT DRP-94-1

2

UNDERSTANDING AND INTERPRETING SEABED DRIFTER (SBD) DATA

by

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DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
3909 Halls Ferry Road, Vicksburg, Mississippi 39180-6199

January 1994

Final Report

Approved for Public Release; Distribution is Unlimited

Prepared for DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000
Under Work Unit 32467

The Dredging Research Program (DRP) is a seven-year program of the U.S. Army Corps of Engineers. DRP research is managed in these five technical areas:

Area 1 - Analysis of Dredged Material Placed in Open Water
Area 2 - Material Properties Related to Navigation and Dredging
Area 3 - Dredge Plant Equipment and Systems Processes
Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems
Area 5 - Management of Dredging Projects

US Army Corps of Engineers
Waterways Experiment Station

Dredging Research Program Report Summary

Understanding and Interpreting Seabed Drifter (SBD) Data (TR DRP-94-1)

ISSUE: With growing concern for environmental quality and the increased recognition of the importance of coastal areas, it is vital that measurements and understanding of coastal processes be improved. Instruments like the electromagnetic and broad-band acoustic doppler current meters have improved the precision of current measurements. Pressure gage arrays effectively measure directional wave spectra. Increased public concern for the environment also permits better data collection at the low end of the technology scale. An example is the voluntary return of inexpensive drogues known as seabed drifters (SBD's) that can be used to map current patterns.

RESEARCH: The study was sponsored by the Dredging Research Program's (DRP) "Field Techniques and Data Analysis" work unit to show how data obtained from SBD studies could be better understood in terms of the dominant coastal processes and how the results could be used to increase benefits associated with properly located dredged material placement sites.

SUMMARY: Proper design of a SBD study should begin by using existing field data and simple models to decide where, when, and how many SBDs should be released based on the study objectives and regional site conditions. Once sufficient return data are obtained, seasonal and spatial variations in current patterns can be investigated using techniques explained here. Because SBD's are released repeatedly in large numbers, they provide information about not only mean currents, but the degree of spread or random dispersion that can be so important in the fate of materials scattered even when mean currents are negligible. Data analysis techniques proposed here are illustrated with real SBD data from the Gulf and Atlantic coasts.

AVAILABILITY OF REPORT: The report is available through the Interlibrary Loan Service from the U.S. Army Engineer Waterways Experiment Station (WES) Library, telephone number (601) 634-2355. National Technical Information Service report numbers may be requested from WES Librarians. To purchase a copy of the repopt, call NTIS at (703) 487-4780.

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Dredging Research Program

Technical Report DRP-94-1
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Understanding and Interpreting Seabed Drifter (SBD) Data

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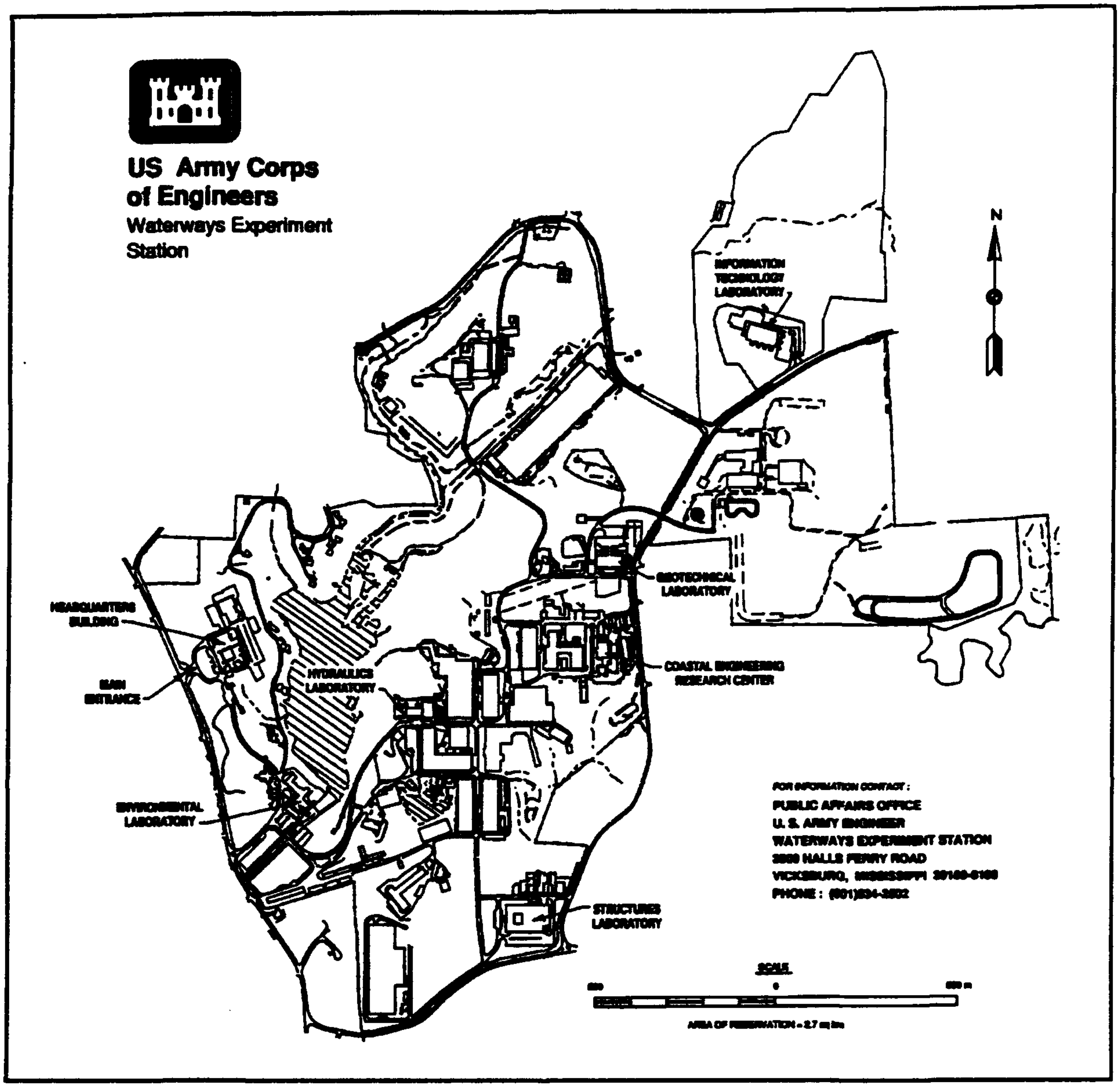

Waterways Experiment Station Cataloging-in-Publication Data

Resio, Donald T.
Understanding and interpreting seabed drifter (SBD) data / by Donald T. Resio [and] Edward B. Hands, Coastal Engineering Research Center ; prepared for U.S. Army Corps of Engineers.
152 p. : ill. ; 28 cm. -- (Technical report ; DRP-94-1)
Includes bibliographical references.
1. Turbidity currents. 2. Anchors, Sea -- Scientific applications. 3. Dredging spoil. 4. Sediment transport. I. Hands, Edward B. II. United States. Army. Corps of Engineers. III. U.S. Army Engineer Waterways Experiment Station. IV. Dredging Research Program. V. Title. VI. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; DRP-94-1.
TA7 W34 no.DRP-94-1

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Preface

The work described herein was authorized as part of the Dredging Research Program (DRP) by Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Work Unit 32467, "Field Techniques and Data Analysis to Assess Open Water Disposal Deposits." The HQUSACE Chief Advisor for the DRP was Mr. Robert Campbell. Mr. Jesse A. Pfeiffer, Jr., was HQUSACE coordinator with the Directorate of Research and Development. Messrs. Glenn R. Drummond and John H. Lockhart were HQUSACE Advisors for DRP Technical Area 1 (TA1), which included Work Unit 32467. The other HQUSACE DRP Technical Monitors were Messrs. Gerald Greener, Barry W. Holliday, David B. Mathis, and David A. Roellig. Mr. E. Clark McNair, Jr., Coastal Engineering Research Center (CERC), U.S. Army Engineer Waterways Experiment Station, was DRP Program Manager. Dr. Lyndell Z. Hales (CERC) was the DRP Assistant Program Manager.

Dr. Nicholas C. Kraus, Senior Scientist, CERC, was Technical Manager of TA1. Work was conducted under the general supervision of Dr. James R. Houston and Mr. Charles C. Calhoun Jr., Director and Assistant Director, CERC, respectively. Mr. Edward B. Hands, Engineering Development (EDD), CERC, was the contracting officer's representative and the Principal Investigator for Work Unit 32467. The final report was written jointly by Dr. Donald T. Resio, Florida Institute of Technology, and Mr. Hands. Dr. Resio worked under contract No. DACW39-90-M-1192. Mr. Hands worked under the direct supervision of Mr. Thomas W. Richardson, Chief, EDD; Ms. Joan Pope, Chief, Coastal Structures and Evaluation Branch, EDD; and Dr. Yen-Hsi Chu, Engineering Applications Unit, EDD. Mr. Douglas M. Pirie, U.S. Army Engineer Division, South Pacific, Mr. Steve A. Chesser, U.S. Army Engineer District, Portland, and Mr. David A. Schuldt, U.S. Army Engineer District, Seattle, reviewed this report and provided helpful comments.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. COL Bruce K. Howard, EN, was Commander.

For further information on this report or on the Dredging Research Program, contact Mr. E. Clark McNair, Jr., Program Manager, at (601) 634-2070.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
inches	0.0254	meters
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	453.5924	grams

Summary

Scientists and engineers have made considerable progress in measurement and prediction of the fate of materials moving in coastal and ocean waters. The U.S. Army Corps of Engineers has participated in these advances and is applying the results to better manage materials dredged from our nation's waterways. Growing concern over environmental degradation and the importance of conserving coastal resources demands continued improvement in understanding coastal circulation systems and the impacts of dredging. Comprehensive management strives to increase the beneficial uses of the dredged material. Choosing the best use often requires understanding the long-term fate of material moving in the open ocean. Some recently developed tools that help expand understanding of sediment fate include improved monitoring guidance, better wave and current sensors, physical models, and numerical simulations. Electromagnetic and doppler current meters, as well as acoustic and optical sediment concentration meters, are examples of sophisticated new field equipment that helps fill data needs. Unfortunately, there are still many areas around the country where basic data are inadequate to properly assess risks and opportunities associated with the use of dredged material.

With greater public involvement in environmental issues, an opportunity also exists to collect more data at the low end of the technology spectrum. Voluntary return of inexpensive drogues, released repeatedly in large numbers, helps map current patterns. Current-following drogues termed "seabed drifters" (SBD's) have been used in oceanographic studies worldwide for decades. The purpose of this report is to investigate how SBD results might be better interpreted in terms of the likely fate of materials moving with coastal waters. Use of SBD's can not only help schedule and locate dredged material disposal at sites that increase secondary benefits, but also could help position ocean outfalls, identify coastal mixing scales, reduce the potential for damaging toxic spills, confirm hydrodynamic models, and clarify the impact of different engineering alternatives on plankton distributions.

The usefulness of SBD data can be increased by designing the SBD release plan to fit the physical processes relevant for specific problems. This report provides the methodology. An overview covers all the potentially important transport mechanisms. Simple parametric models are described for estimating which mechanisms are likely to dominate in different coastal areas. The

understanding of the dominant processes provided will help guide the SBD release plan.

In addition, new techniques are given for understanding SBD recovery patterns. Separation of different scales of motion indicates which analysis procedures are most appropriate (e.g., different sample stratifications and temporal smoothing). Procedures are established for resolving a deterministic and a random component of flow from the dispersion of bundles of SBD's. The relative importance of mean and random components can vary widely and is valuable for explaining transport variations and the likely spread of material from different areas and at different times. The analysis techniques are illustrated using extensive data collected from one area in the Gulf of Mexico and another on the East Coast. Conclusions are validated by comparing these SBD interpretations with other measurements and model results.

The guidance presented in this report should increase the usefulness of data obtained using standard SBD's. Recommendations are also given to improve SBD's particularly for the study of coastal sediment movements.

1 Introduction

Background

For many years engineers and scientists have been searching for an effective, relatively inexpensive means of determining the fate of materials placed in the coastal and offshore environment. With the growing concern about environmental degradation related to man's activities and the increased recognition of the importance of the coastal and offshore region to global-scale ecosystems, the need for improved information in these areas has become vital. Many tools for predicting the fate of materials have evolved through the years. These include sophisticated instrumentation, numerical models, and long-term databases. All of these tools can play a role in the assessment of potential problems related to the placement of materials offshore; however, in many areas around the United States, sufficient information required to evaluate possible hazards clearly and quantitatively still does not exist. To meet one aspect of this need, researchers have been using various types of in situ drifters to follow the motions of the near-bottom water column. In particular, current-following drogues termed "seabed drifters" (SBD's) have been used extensively to gather data on bottom water motions. Table 1 shows a list of a number of such studies that have been conducted around the world (Hands 1987).

Purpose

The purpose of this report is to investigate how data obtained from routine SBD recoveries might be interpreted and understood in a fashion that leads to an improved assessments of the fate of materials in the open ocean. Such information is valuable for guidance pertaining to:

a. The location of outfall sites.

b. The fate of dredged materials.

Table 1
Chronological Listing of SBD Information from Partial Review of the Literature

Study Location	Total Released	%Rec[1]	Weight grams[2]	Reported Reward[3]	Approx. 1986 $[4]	Reference
Humber Estuary, England	590	37		$0.25	$1.00	Robinson (1968)
Chesapeake Bay Entrance	9,800	17		$0.50	$2.00	Norcross and Stanley (1964)
Lake Erie	368	24	5			Hartley (1968)
Morecambe Bay	300	36	14	$0.25	$1.00	Phillips (1968)
Irish Sea	500	34	10	$0.25	$1.00	Harvey (1968)
English East Coast	24,500	16				Lee, Bumpus, and Lauzier (1965)
Morecambe Bay	200	76	7	$0.25	$1.00	Phillips (1969)
NC Shelf, North of Cape Hatteras	635	22	5-7			Schumacher and Korgen (1976)
Raleigh Bay, NC Shelf	810	29	5-7			Schumacher and Korgen (1976)
Onslow Bay, NC Shelf	3,020	21	5-7			Schumacher and Korgen (1976)
Long Island Sound	360	36	5			Gross and Bumpus (1972)
Liverpool Bay	6,625	79	7	$0.25	$0.75	Halliwell (1973)
San Francisco Bay	1,345	18	5	$0.50	$2.00	Conomos (1974)
East Anglia Coast	600	63		$0.25	$0.75	Riley and Ramster (1972)
Tuscan Coast, Cecina, Italy	945	80	6	1000 Lire	$1.63	Bartolini and Pranzini (1977)
Long Island Sound	797	36				Paskausky and Murphy (1976)
Central California Coast	2,250	23		$0.50	$1.00	Griggs (1974)
Port Phillip Bay and Approach	2,000	27				Sternberg and Marsden (1979)
New York Bight	4,076	30				Charnell and Hansen (1974)
Bristol Channel, England	1,350	57	7			Collins and Ferentinos (1984)
Ocean off Cape Cod	1,800	12		$0.25	$0.50	Collins, Griscom, and Hoffman (1978)

1 %Rec: Percent of released SBD's that were recovered by the end of the reported study.
2 Weight, grams: Weight of the formula attached to the stem to overcome the buoyancy of the plastic.
3 Reported Reward: Money offered for return of each SBD. Blank if no reward was offered.
4 Equivalent 1986$: Approximately equivalent value of reward in 1986 dollars.

Table 1 (Concluded)

Study Location	Total Released	%Rec	Weight grams	Reported Reward	Approx. 1986 $	Reference
Delaware Bay and shelf	7,000	11	5 to 6			Pape and Garvine (1982)
San Diego Bay and shelf	497	29	5	$0.50	$0.50	Hammond (1982)
Grays Harbor and coast	2,000	14				Schuldt (1981)
Hilton Head Island, SC	200	50				Henry (1984)
Georgia Shelf	1,000	60	7	$1.00	$1.25	U.S. Army Engineer District, Savannah (1983)[1]
Kuwait Bay	1,200	2				Lee and Samuel (1982)
Continental Shelf off Oregon	894	6	7	$1.00	$1.00	Zirges (1983)
Monterey Bay, CA	231	12	7			Squire (1969)
New York Bight	2,190	32				National Marine Fisheries Service (1972)
Duck, NC	325	54	6&11			Hands (1987)
Off Suislaw River, OR	613	46	6			Hicks and Babcock (1988)
Dauphin Island, AL	2,700	17	7&14			Hands and Bradley (1990)

[1] U.S. Army Engineer District, Savannah. (1983). Files on investigations of Savannah and Brunswick Harbor Disposal Sites (unpublished). Citations for published reports are in References section of this report.

c. Decision-making related to offshore contaminants (oil spills, toxic wastes, etc.).

d. Understanding and modelling transport and mixing processes in coastal and offshore areas.

e. Confirmation of hydrodynamic models.

Previously, information on SBD recovery patterns has been used primarily in a "stand-alone" fashion to derive empirical estimates of the eventual spatial dispersion of SBD's released from one or several stations. This report will show that the understanding of SBD recovery data can be enhanced by viewing the data within the context of the relevant physical processes and by including information from simple parametric models of the dominant processes. The principal data set which will be examined in this study is based on SBD releases made off the Alabama coast in the vicinity of several recently constructed, dredged material berms (Figure 1). Hands and Bradley (1990) discussed recovery data from the first 9 release episodes. Releases continue periodically at this National Berm Demonstration site and the SBD recovery information now seems reasonably complete for the first 19 release episodes. These returns, covering a two-year period, will be used to illustrate methods of interpreting SBD results. While site-specific analyses of processes, scales of processes, and available data focus on the Mobile Bay area, an attempt will be made to remain as general as possible.

Organization of Report

Several processes may be operative in the offshore and coastal area and act as forcing functions for the observed SBD motions. In general, only the locations of the initial release site and the recovery site are known, and nothing is usually noted of the actual path taken by an SBD between the two locations. Consequently, the analysis should concentrate on processes at the spatial and temporal scales represented in the recovery data. Since recoveries from most experiments demonstrate motions on the scale of miles and days, consideration of microscale, convective-scale, and mesoscale phenomena is needed only to the extent that they contribute to a net circulation; however, their effect is captured as a scatter in data. A measure of this apparently random component of motion will be defined to quantify the magnitude of the net effects of the smaller scale processes.

In order to address the several processes that may be moving the SBD's, this report is organized as follows:

a. Chapter 2 — Description of the generalized processes which might influence SBD motions, including a scale analysis of the expected magnitudes of projected motions.

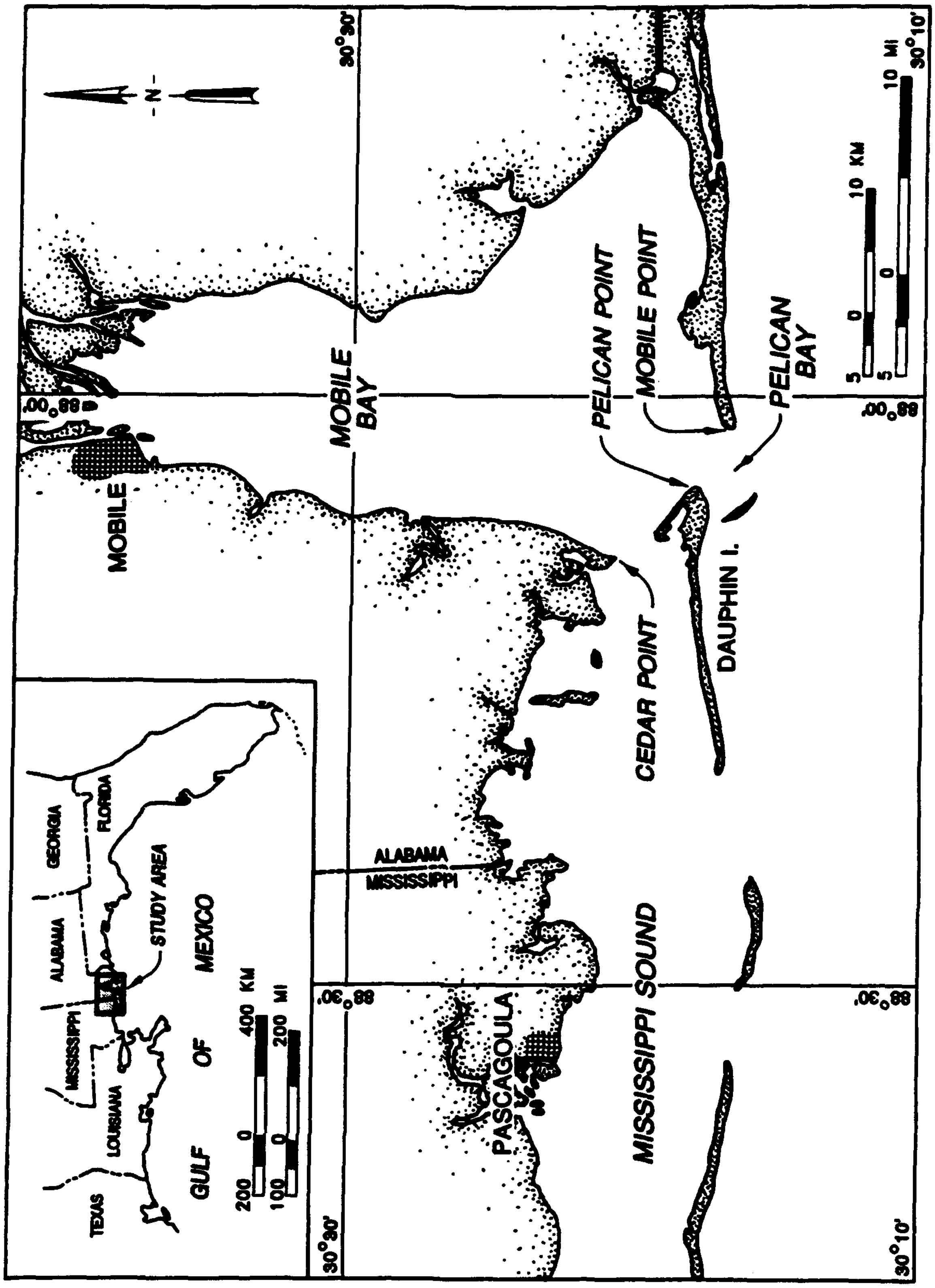


Figure 1. Mobile Bay location map (Hands and Bradley 1990)

b. Chapter 3 — Results of some simple modelling to quantify the dominant processes at intervals following the releases.

c. Chapter 4 — Analysis of the SBD data using temporal and spatial stratification to clarify certain process-response relationships.

d. Chapter 5 — Identification and quantification of random and deterministic components in the SBD patterns and their relationship to appropriate driving forces.

e. Chapter 6 — Discussion and conclusion sections which address the major findings.

Appendix A, contained in this volume, gives a theoretical basis for the equation used to estimate coastal currents driven by open coast waves. Appendix B, also contained in this volume, is a listing of symbols and abbreviations used in the report. Appendices C through E are contained in a separate volume, which may be obtained from the U.S. Army Engineer Waterways Experiment Station or the National Technical Information Service. Appendices C and D contain time series of hindcast waves and currents, and Appendix E shows graphical representations of smoothed recovery patterns. Appendix F shows the graphic results of a contingency analysis of relative wind and wave effects on SBD displacement for each of the 19 episodes.

2 Analysis of Processes Affecting SBD Motions

Before beginning the treatment of various processes that can affect synoptic-scale and large-scale motions of the SBD's (i.e., process scales in miles and days consistent with the recovery patterns), it is instructive to examine the local forces on the SBD's. Figure 2 shows a typical SBD, along with a diagram of the forces acting on it. Also shown is a "blowup" diagram of sediment particles and the relevant forces. Since weights can be added to or subtracted from the SBD, the specific weight of the SBD can be made to match that of a sediment particle; therefore, buoyancy and related effects could be made comparable. However, two fundamental differences are immediately apparent in Figure 2. First, the surface area of the cap of the SBD is about three orders of magnitude greater than that of a sediment particle; therefore, the total drag acting on the SBD is certainly much greater than that acting on a single sediment particle. Second, and probably more important, the dominant forces acting on the SBD are expected to be located at its region of maximum surface area, which is located about 0.5 m above the bottom. For sediment particles, the dominant forces would be located at the 0.005-m level, assuming even a "large" 1-cm particle. Thus, the forces acting on the SBD are primarily outside the bottom boundary layer; whereas, the forces acting on a sediment particle occur within the bottom boundary layer. In particular, the vertical velocities and accelerations should be markedly different between the two levels. At the 0.5-m level, wave motions should still contain a significant vertical component; whereas, at the 0.005-m level these motions should be entirely negligible. Hence, the ratio of restraining drag (which is located only at the small bottom of the stem of the SBD) to the forcing drag should be extremely different between the SBD and sediment motions. For this reason, the motions of the SBD's, as currently designed, should probably be regarded as more indicative of motions of materials suspended in the near-bottom water column than of actual bottom materials. Hands and Sollitt (in preparation) discuss adjusting the weight of the ballast on the SBD stem so that the SBD does not begin moving until currents are intense enough to suspend specific grain sizes.

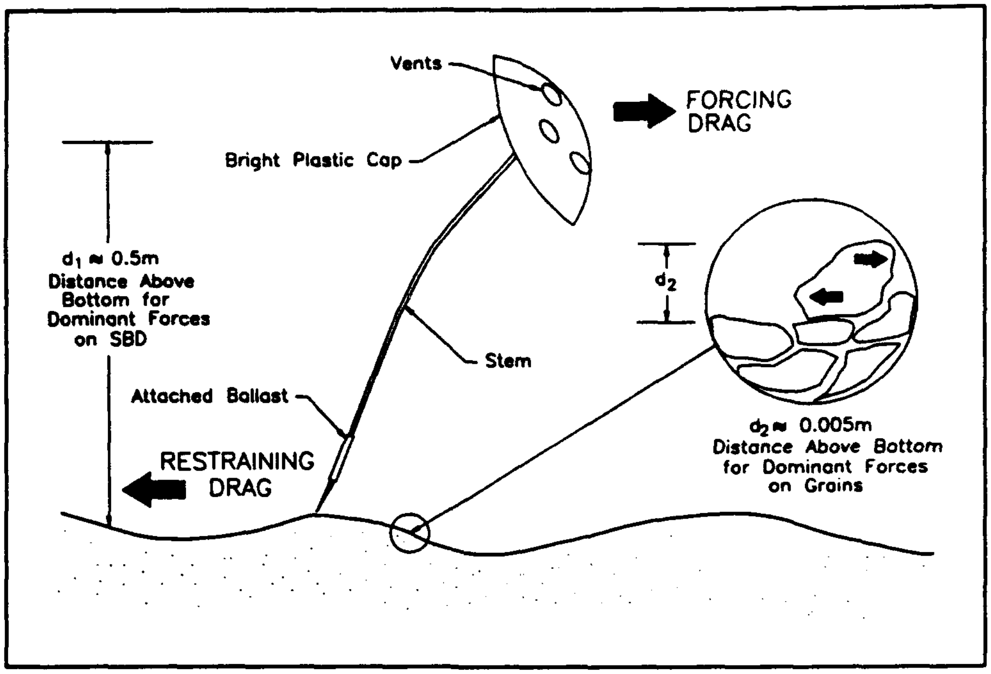


Figure 2. Differences in scales and forces on a Woodhead SBD and a sand grain

Description of Processes

In general, the six types of processes that can be found to force the motions of SBD's in coastal areas are:

a. Gravity-driven flows in two-layer systems.

b. Riverflows.

c. Waves.

d. Astronomical tides.

e. Wind-driven currents.

f. Large-scale ocean circulation patterns.

According to Pape and Garvine (1982), even in partially-mixed estuaries the role of a gravity-driven flow can be very important in controlling the motions of near-bottom water. This type of flow tends to take near-bottom water from offshore areas and bring it into large bays. In Figure 3, Pape and Garvine show that this flow pattern is well established in the Delaware Bay area, with SBD released offshore ending up in the Bay. Apparent trajectories extend from the release sites (numbered points) to the recovery sites.

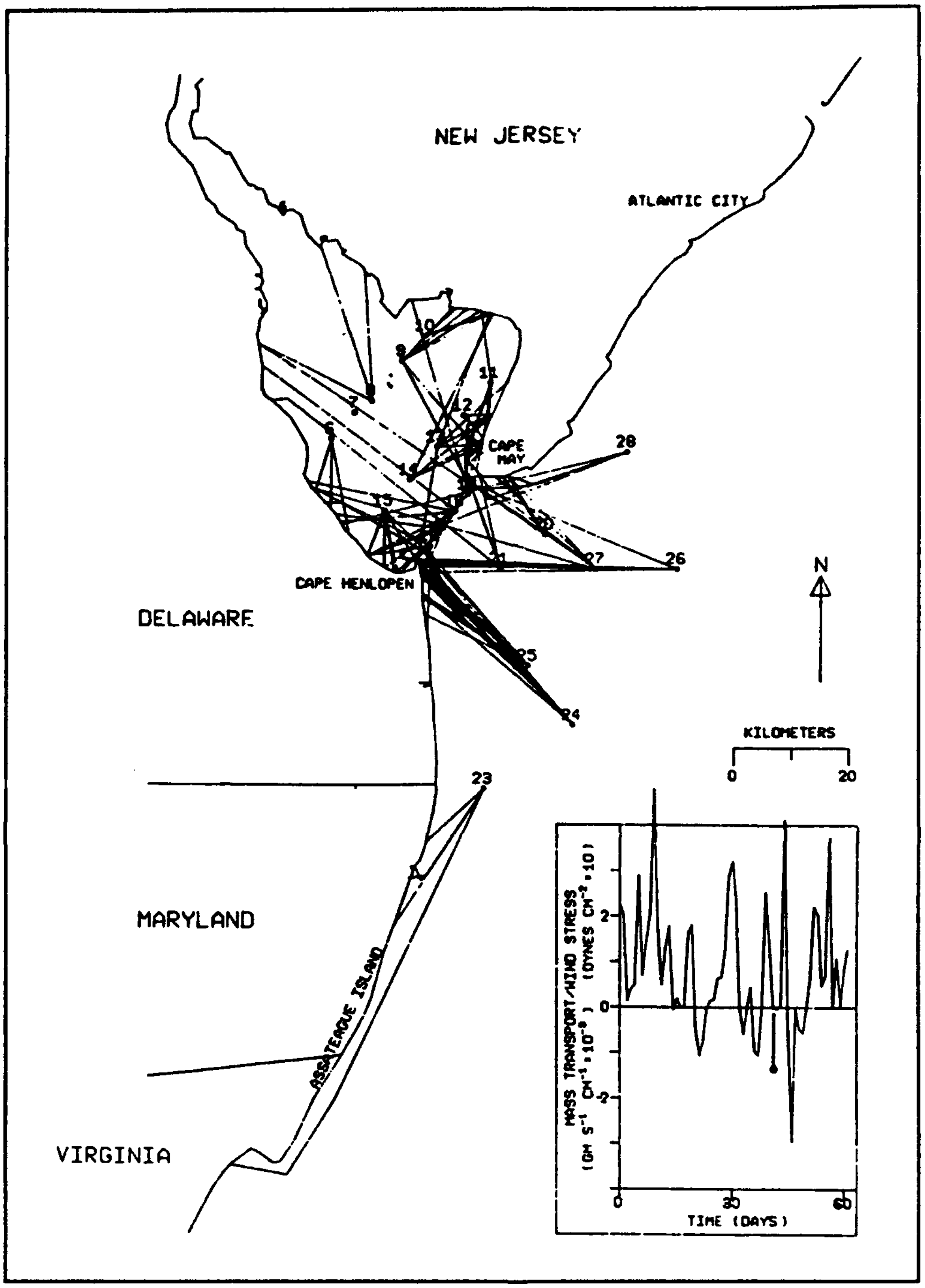


Figure 3. Apparent trajectories of SBD's in November in Delaware Bay region (Pape and Garvine 1982)

Inside estuaries the effects of riverflows can be important. Consideration of mass fluxes shows that the velocities will tend to be highest in the more constricted portions of the estuaries and will become lower as the cross-sectional area available to accommodate the flow becomes larger. Once beyond the mouth of the bay or inlet into the offshore region, the available

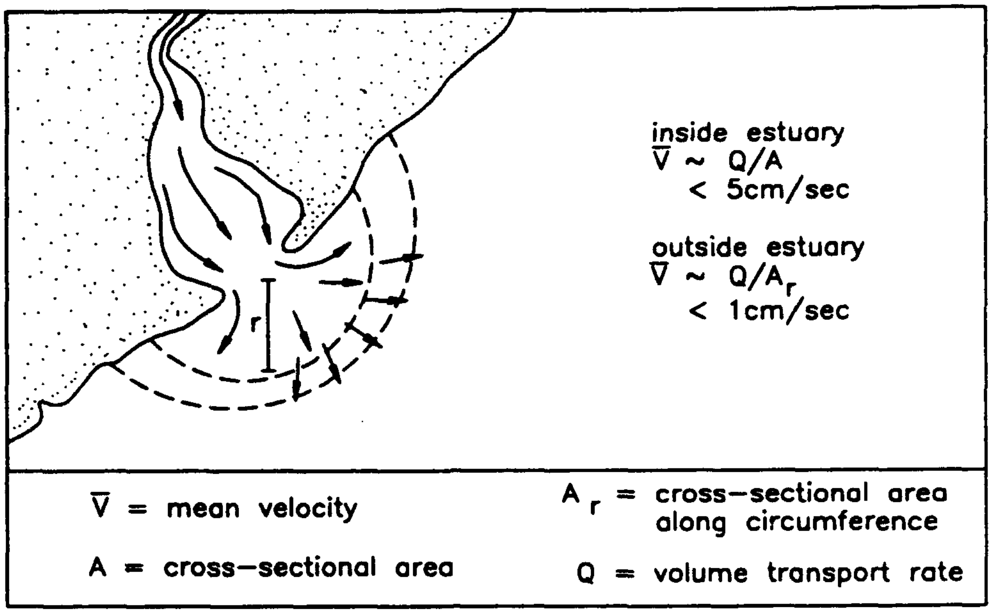


Figure 4. Schematic diagram of river-driven currents in coastal areas

cross-sectional area should scale in proportion to the radial distance outward from the mouth as seen in Figure 4. Thus, the water motions in offshore areas which are driven by riverflows are in general expected to be small. The formation of "jets" can sometimes extend significant flow velocities well offshore, but these high velocities are typically restricted to surface waters and do not extend into the near-bottom water column.

Wind-generated surface waves have long been recognized as playing a major role in the transport and dispersion of materials in the coastal and offshore environments. Outside the surf zone the near-bottom orbital velocities are important for initiating motions of bottom materials. In instances where the mean currents are not sufficiently strong to exceed the threshold for initiating motion, waves can nevertheless induce a significant transport of materials. The actual mean current generated by the waves themselves, the so-called mass transport velocity, is typically about two orders of magnitude lower than the orbital velocities, since it relates to a higher-order nonlinear interaction with the bottom boundary layer. Once waves begin to break close to the coast, they begin to contribute to large net motions via a radiation stress mechanism. This effect leads to wave setup and longshore currents inside the surf zone. Figure 5 diagrams mass transport and longshore currents for a hypothetical coastal area.

Astronomical tides drive large currents under certain conditions. Because tides are governed by "longwave" equations, tidal currents extend into the near-bottom and can create significant velocities in that region. In general, however, the highest tidally-driven velocities occur in restricted passes joining bays, sounds, and large estuaries to the ocean, as can be seen by examining the tidal current vectors for the Mississippi Sound area shown in Figure 6.

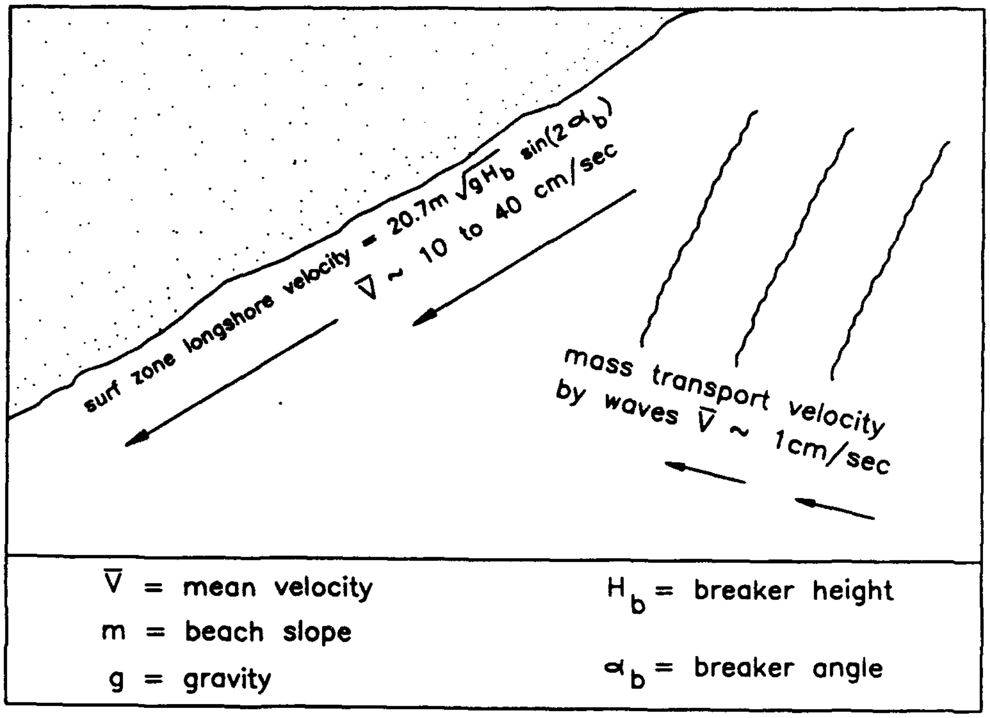
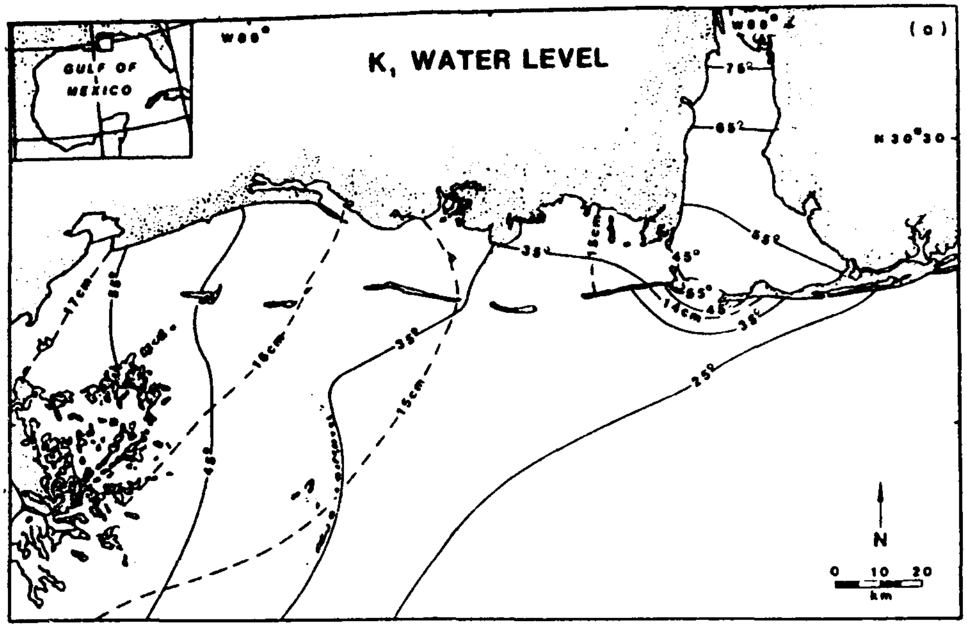


Figure 5. Schematic diagram of two types of wave-driven currents in coastal areas

Wind-driven currents can represent an extremely complicated process in areas where there is significant thermal or salinity stratification. In most near-coastal areas, however, the higher velocities (which are most likely the velocities considered important for material transports and dispersion) are related to wind events that force the entire water column to be mixed down to depths of 30 to 40 m. Hence, predicting the fate of materials in the coastal environment is sometimes possible using a fairly simple, single-layer model. As shown by Murray (1975) via theoretical and empirical means, these wind-driven coastal currents tend to flow parallel to the coast in almost a slab-like fashion (Figure 7).

On a global scale, physical processes are driven by differences in water temperatures and salinities. These density-driven currents attain a quasi-balance with Coriolis accelerations and can create large regions of high currents, such as the Gulfstream and Humboldt Currents. In Figure 8, which presents a cross-sectional diagram of currents for a transect across the Gulf of Mexico, these large-scale currents tend to be largest in organized "jets" that may be thousands of feet thick and have current maxima located well off the coast (typically 40 to 100 miles from shore).



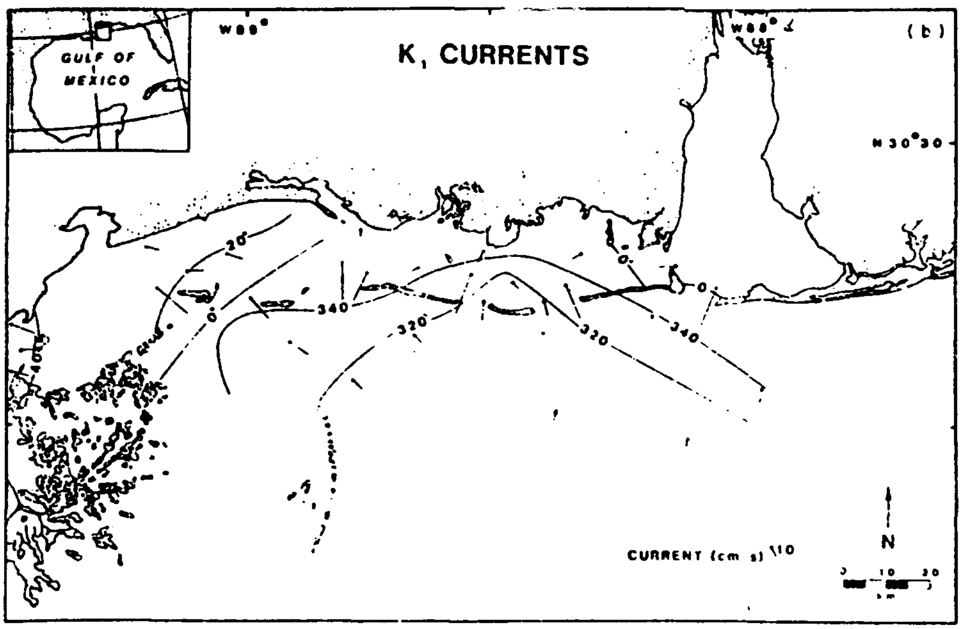
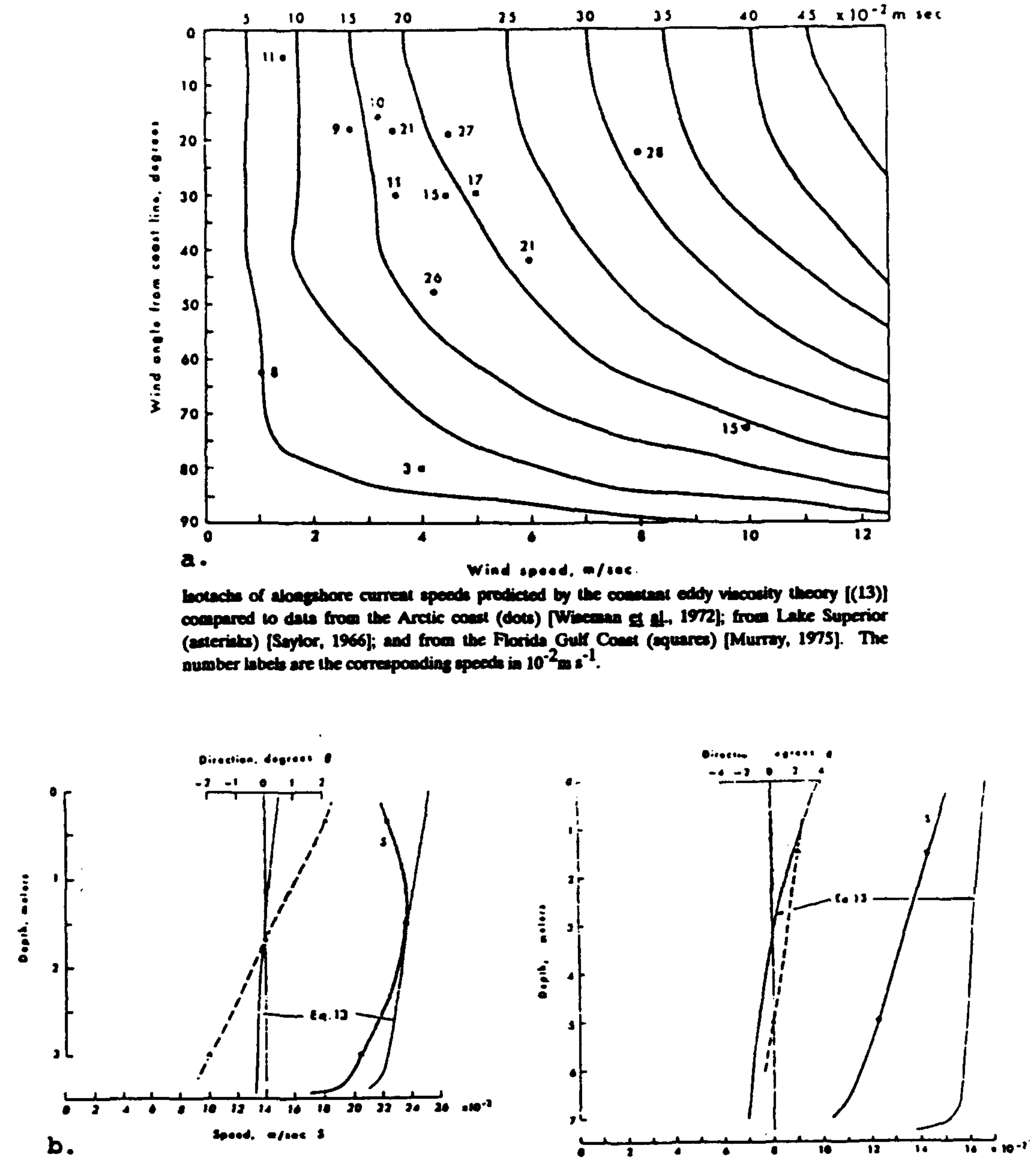


Figure 6. Cotidal chart of the K_1 partial water level tide (a) and current (b); —, Isopleths of Greenwich phase, G(°); ---, Isopleths of amplitude, H(cm). Arrow length represents surface major axis current amplitude, and orientation gives direction at maximum flood tide (Seim, Kjerfve, and Sneed 1987)



a. Isotachs of alongshore current speeds predicted by the constant eddy viscosity theory [(13)] compared to data from the Arctic coast (dots) [Wiseman et al., 1972]; from Lake Superior (asterisks) [Saylor, 1966]; and from the Florida Gulf Coast (squares) [Murray, 1975]. The number labels are the corresponding speeds in 10^{-2}m s^{-1}.

b. Speed and direction of currents observed by Saylor (1966) in Lake Superior on 4 September under winds of 8 m s^{-1} at 30° to the coastline compared to prediction of constant eddy viscosity theory [(13)], shown as light lines. Current direction is measured from parallel to shoreline, positive onshore.

c. As in figure at left, except for measurements on 11 September under winds of 10m s^{-1} at 73° to the coastline.

Figure 7. Wind-driven coastal currents (Murray 1975)

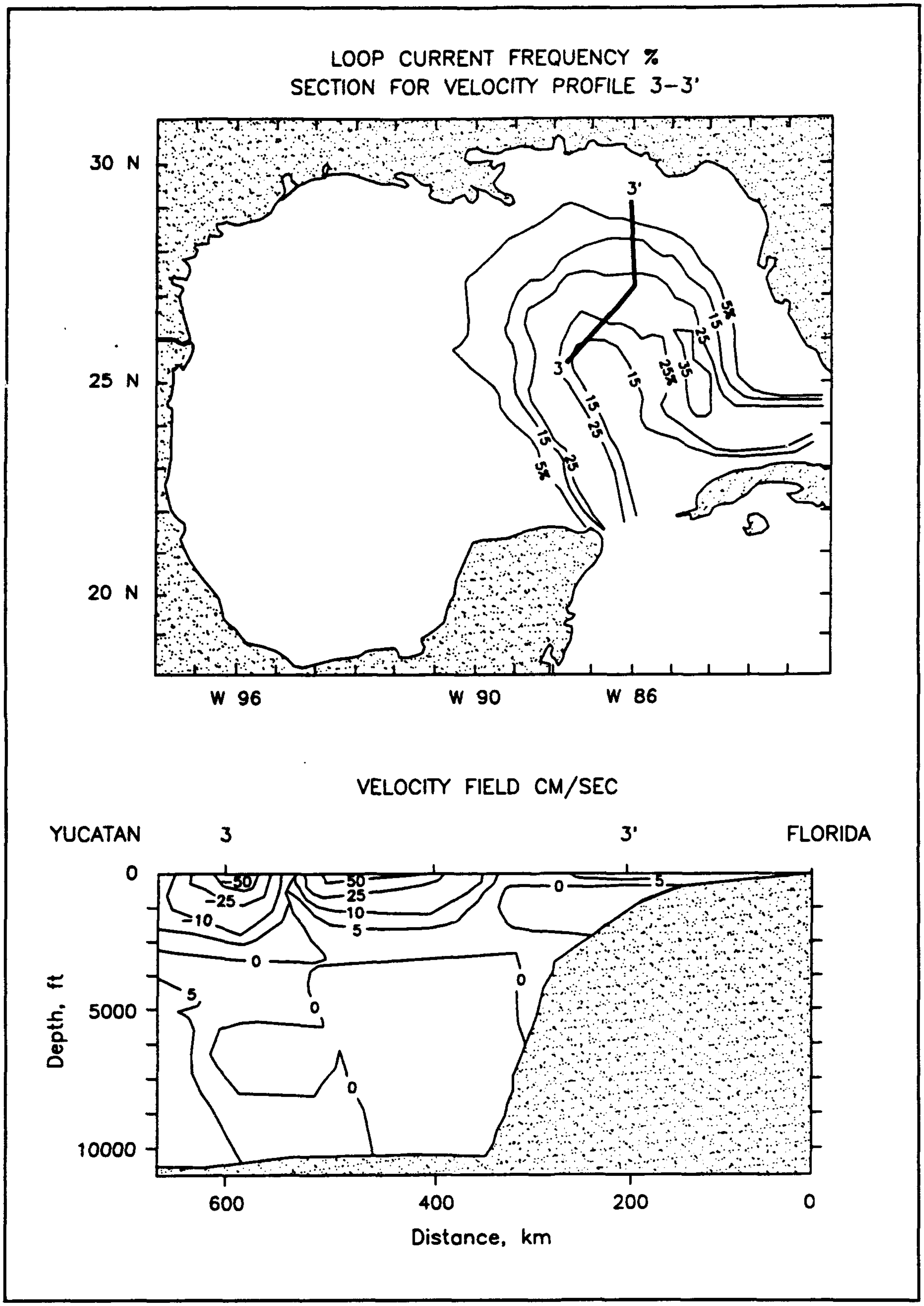


Figure 8. Velocity profile for a section across the Gulf of Mexico from the Florida panhandle to Yucatan (Hofmann and Worley 1986)

Scales of Processes

Because the scales of physical processes are site-specific, attention in this section is directed to processes in the Gulf of Mexico where coastal SBD data are most extensive.

Gravity-driven two-layer flows

As noted in Figure 3, the flow pattern associated with the type of two-layer flow found in some areas can extend 30 kilometers offshore or more. From the study by Pape and Garvine (1982), typical near-bottom, ocean velocity scales are of the order of 10 cm/sec.

Riverflows

Inside large estuaries, the cross-sectional area is usually sufficient to reduce fluvially-driven velocities to only a small percentage of their values in strictly riverine areas. Typical near-bottom velocities inside the estuary are on the order of 1-5 cm/sec. Once offshore, the near-bottom flows due to river forcing are typically less than 1 cm/sec. In the area off Mobile Bay, it is expected that near-bottom currents due to riverflows should be negligible. Inside Mobile Bay, currents during periods of major flooding may become of some significance but probably do not contribute much to the overall transport of bed materials inside the Bay because of their limited duration.

Wave-induced currents

As discussed previously, wave-induced currents can be separated into mass transport currents and longshore currents. Outside the surf zone the general mass transport velocities are on the order of only 1 cm/sec or so. Because the mass transport is related to rather weak nonlinear interactions between the waves and the bottom, it is not possible for these currents to become much larger than about 3 percent of the orbital velocities. Inside the surf zone, which extends only to depths equal to about the incident wave height (typically only 50 to 100 m from the coast, except during storms), the currents usually range from 10-40 cm/sec. However, during storms the spatial extent of the surf zone may extend as much as a kilometer (km) off the coast, and the velocities can reach 100-200 cm/sec. Hence, inside the surf zone, the wave-driven (longshore) currents can be seen to be the dominant mechanism for transporting materials; whereas, beyond the surf zone, mean wave-driven currents can typically be neglected.

Astronomical tides

Tidal currents vary in magnitude and direction during each tidal phase. Near inlets and other constricted passes between large embayments and the open ocean, tidally-driven currents can attain high velocities, on the order of 300-500 cm/sec, in extreme cases. More typical speeds in such constrictions range from 20-50 cm/sec as seen in Figure 6. In the offshore area, tidally-driven near-bottom speeds tend to be considerably lower than in constricted flow regions, typically only about 5-15 cm/sec in the Mobile Bay region. Figure 9 shows that the diurnal tidal velocities on the Alabama shelf are in this range.

Wind-driven currents

As shown by Pickett and Burns (1988) in Figure 10, several current measurements have been taken in an area about 75 km east of our primary region of interest. Because the bottom materials are roughly comparable and the offshore slopes are similar, the currents in the Mobile Bay offshore area should respond similarly to currents depicted in these measurements. Pickett and Burns (1988) concluded that the primary offshore currents were, in fact, driven by wind forcing (roughly accounting for 90 percent or more of the total currents). Figure 11 from their study shows that these currents can attain speeds in the 30-60-cm/sec range. Consequently, these currents should play an important role in transporting suspended materials in offshore areas in depths out to about 30 m or so (about 10-20 miles offshore).

Large-scale circulation patterns

As previously seen in Figure 8, large-scale currents in the Gulf of Mexico contain regions where average speeds are greater than 50 cm/sec. However, in the Mobile Bay area, the speed of the net circulation is less than 5 cm/sec. Thus, for the Alabama coastal region large-scale thermal circulation can likely be neglected.

Dominant Processes in the Mobile Bay Region

An analysis of process scales in the Mobile Bay area suggests that direct wind forcing is the dominant open-coast process which generates near-bottom mean currents. Inside a small region adjacent to the coast, waves are expected to become the dominant process; while in inlets and passes, tides

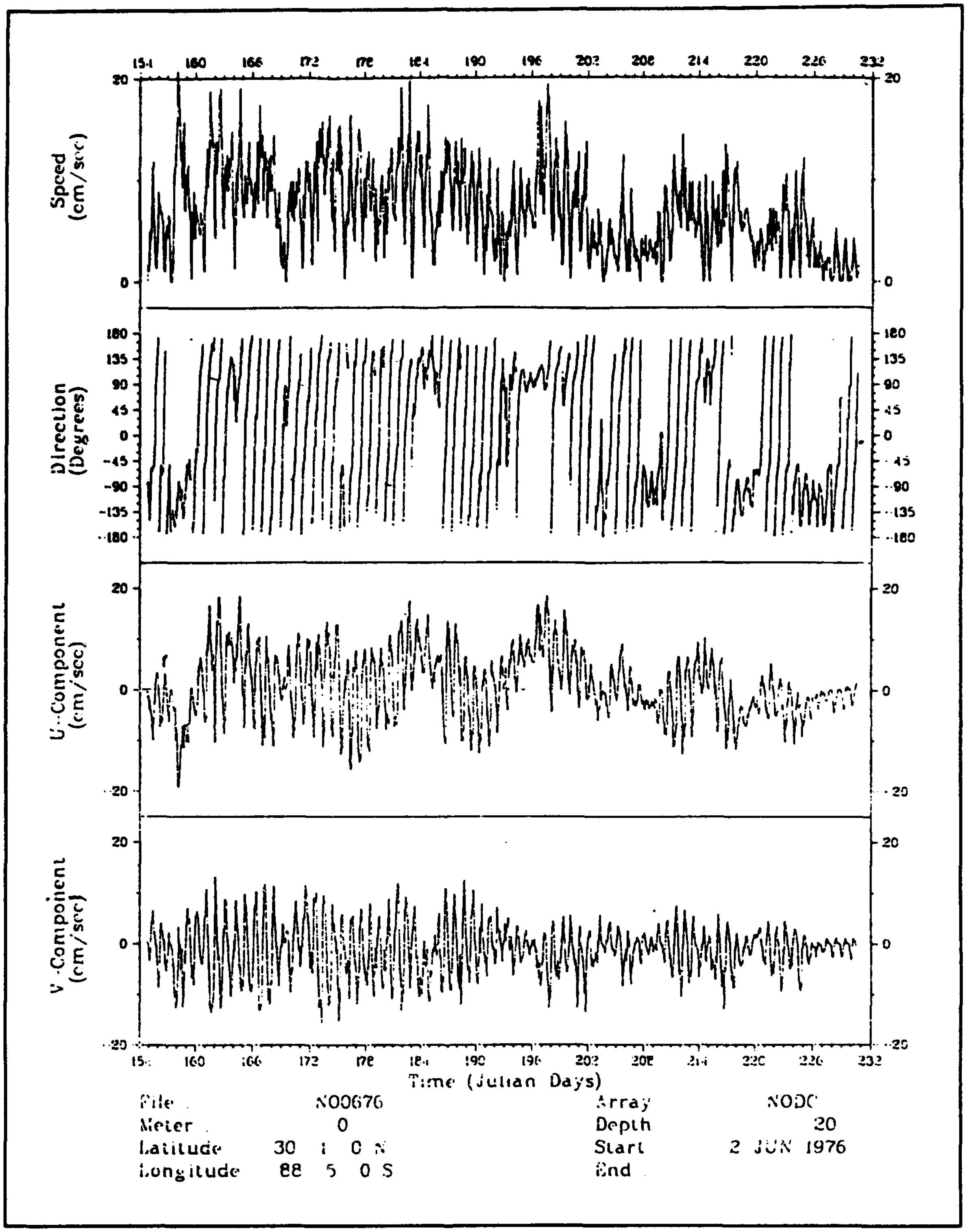


Figure 9. Currents measured in water depths of 20 m on Alabama shelf in the summer of 1976 (Plot provided by Dr. Rudy Hollman, U.S. Navy, Naval Ocean Research & Development Activity, NSTL, MS, using data collected by Dr. W. W. Schroeder, Marine Science Program, University of Alabama, Dauphin Island, AL)

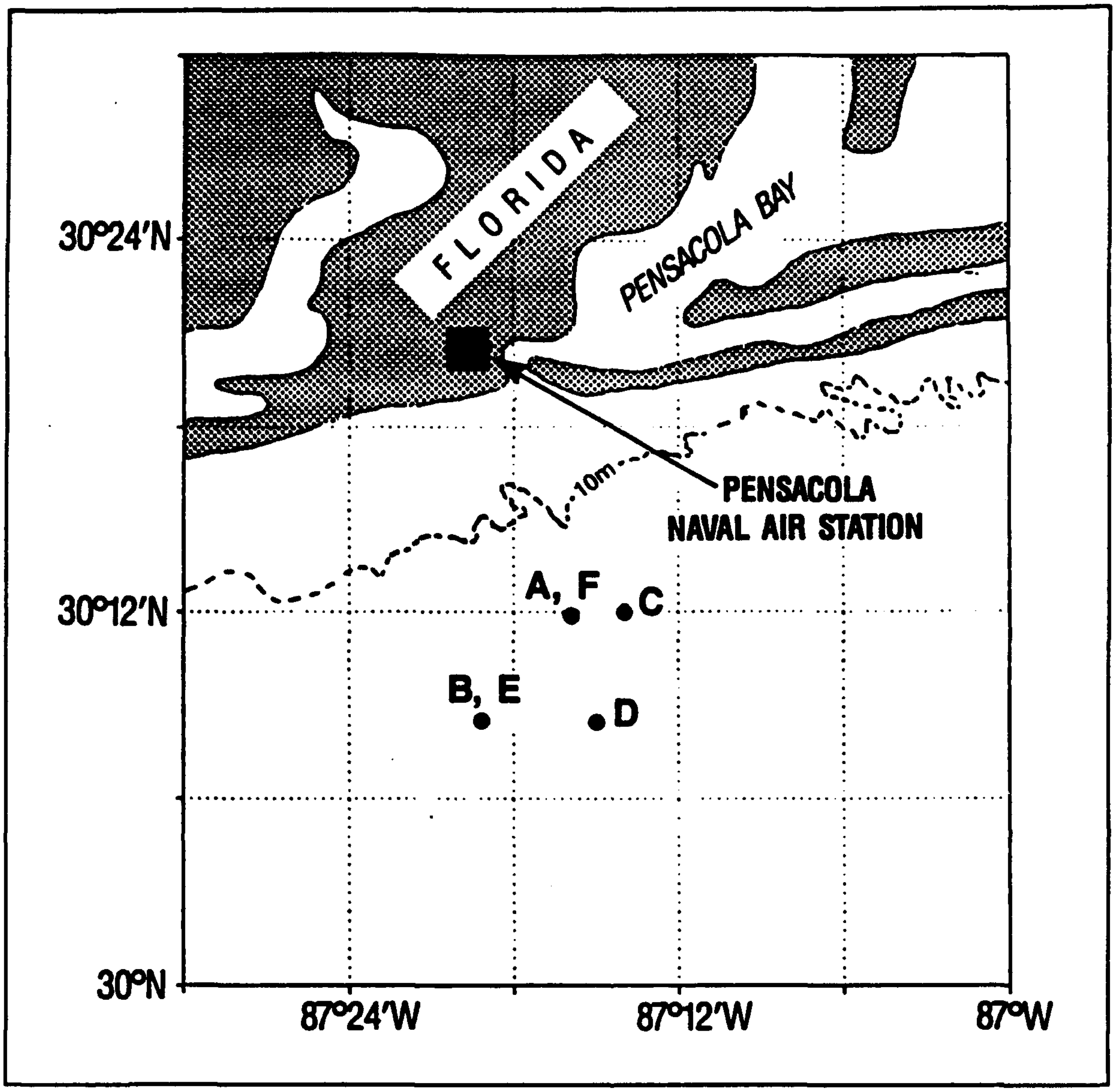


Figure 10. Six current meter sites south of Pensacola, Florida. Arrays A, F, and B, E, were at the same location but were deployed at different times. Site water depths ranged from 20 to 24 m. Two current meters (9 m below the surface, and 4 m above the bottom) were deployed at each site; one additional current meter was deployed 1 m above the bottom at Array E (Pickett and Burns 1988)

play a major role in determining the fate of materials injected into the water column.

Since winds generate both waves and currents, it is instructive to separate the responses to these two processes to various wind forcing. Surface waves are generated approximately along the same direction as the wind.

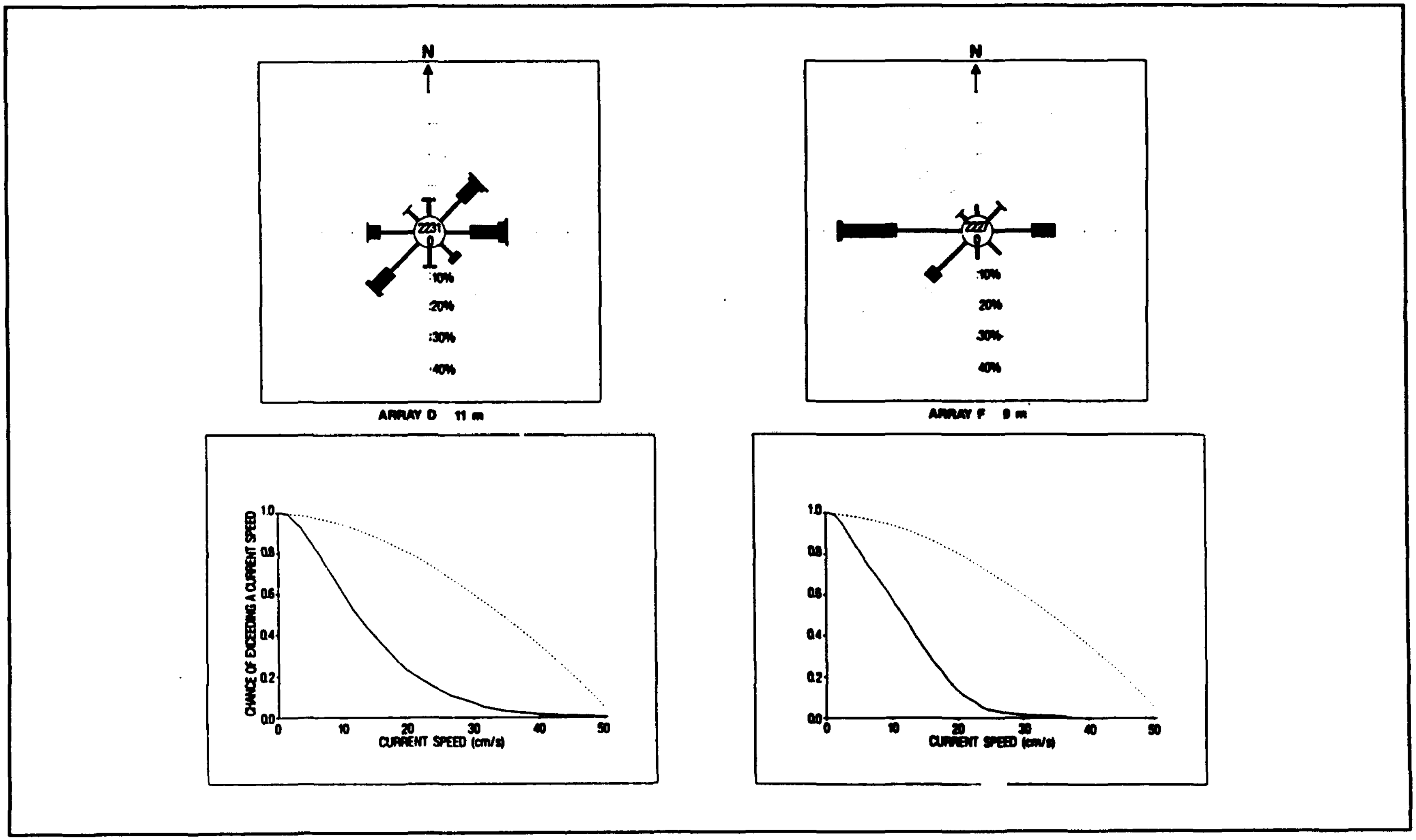


Figure 11. Current rose (upper panel) and speed probability distribution (lower panel) for specified array at the depths shown; dotted circles on rose show percent frequency of current by direction (towards); thickness of bar indicates speed of current: 0-15 (thinnest bar), 15-30, 30-45, and greater than 45 cm/s; numerals inside of the rose show the number of hourly averages used and the percentage of zero speeds; the solid line in the lower panel is for currents observed and the dashed line indicates faster speeds for modelled currents over the long term from 1948 to 1987 (Pickett and Burns 1988)

There can be some deviation, maybe even up to 30 deg, but this difference between the wind and waves persists only for limited times (a few hours) following frontal passages or in very oblique fetch geometries. Hence, winds blowing away from the coast generate waves that propagate away from the coast. The resulting waves at the coast should be negligible from such a local wind system, but swell waves (i.e., waves that were generated in another area and have passed out of their region of generation) may still be coming into the coast. Consequently, a storm with onshore winds will tend to generate high-speed longshore currents whose directions strongly correlate with the wind's longshore component; and storms with offshore winds will, at their strongest, tend to generate only weak longshore currents. In contrast to the situation with waves, direct wind-driven currents exhibit symmetric and almost equal velocity response to wind forcing in the onshore and offshore directions. Approximate functional relationships for wave-induced longshore currents V_{waves} (see Appendix F) and wind-driven currents V_{winds} can be written as

$$V_{waves} \propto U^p \phi_1 (\theta) \tag{1}$$

$$V_{winds} \propto U^q \phi_2 (\theta) \tag{2}$$

where

V_{waves} = speed of longshore flow outside the surf zone that is driven by the waves

V_{winds} = speed of longshore flow driven directly by the winds

U = windspeed

p = exponent dependent on sea state, but close to 2 for fully developed waves

q = exponent approximately equal to 1

ϕ_1 = coefficient of proportionality that is a function of wind angle as given in Figure 12

ϕ_2 = coefficient of proportionality that is also a function of wind angle as given in Figure 12

θ = angle between wind vector and shore normal. A positive 90 deg indicating wind blowing along the shore in the direction of the positive current, i.e., toward the east in this study.

The basis of these relationships is given in Appendix E. For simple parametric estimates of wind-driven currents, the following relation is more useful:

$$V_{winds} = 0.038\ U\ \phi_2'(\theta) \tag{3}$$

where

$$\phi_2' = \frac{0.14 + \cos^2(\theta - \pi/2)}{1.14}$$

The speed of the wind-driven current given by Equation 3 is in the same units as the wind speed because ϕ_2' is dimensionless. The variation in ϕ_2' with wind direction is also shown in Figure 12.

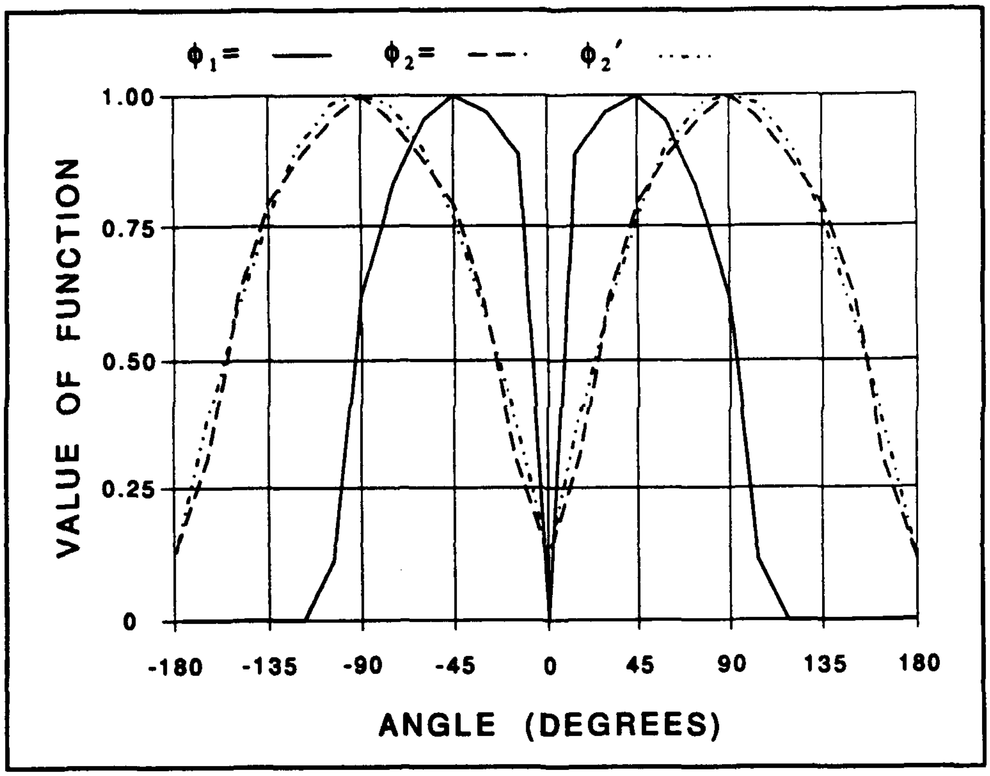


Figure 12. Functional behavior of ϕ_1, ϕ_2, and ϕ_2'

3 Quantification of Processes During Specific Release Episodes in Mobile Bay

As pointed out in the previous section, three of the possible six forcing functions tend to dominate the near-bottom currents in the Mobile Bay area--tides, waves, and winds. Because Figure 6 already contains a reasonable synthesis of the tidal velocities in our region of interest, there is no real need to perform any additional modelling for these currents. On the other hand, there is little available information on waves and wind-driven currents during the release periods. Long-term prototype data collection is under way at this site, but only short-term results are presently available. Hence, both a wind-driven current model and a wave model will be exercised to obtain some quantitative estimates of these processes during the two-year interval of interest. To explain recovery patterns for the release episodes shown in Table 2, the waves and currents were hindcasted for the period from March 1987 to October 1989.

Wind Estimates

It is beyond the scope of this study to construct careful wind fields over the entire Gulf of Mexico for a two-year interval. However, because of the absence of a major source for frequent swell inside the Gulf of Mexico, most of the waves are locally generated. The wind-generated currents are also a "local" process, so a parametric wind field based only on transformations of coastal land-station winds should suffice. The parameterization is consistent with the methodology developed by Resio and Vincent (1977) and was used in a study for the Navy to estimate winds that drove predictive current models for a similar area of the Gulf with good results (Pickett and Burns 1988).

Table 2 Sand Island SBD Release Episodes		
Release Episode	Number Released	Date of Release
1	300	3 Mar 1987
2	300	19 Mar 1987
3	300	31 Mar 1987
4	300	15 Apr 1987
5	300	5 May 1987
6	300	11 & 17 Aug 1987
7	300	20 Aug 1987
8	300	1 Dec 1987
9	300	7 Jan 1988
10	300	25 Feb 1988
11	300	14 Apr 1988
12	300	26 May 1988
13	300	2 Aug 1988
14	300	14 Sep 1988
15	300	20 Oct 1988
16	300	20 Jan 1989
17	300	20 Mar 1989
18	300	7 May 1989
19	300	6 Jun 1989

Wave Estimates

To convert wind estimates into waves, the time interval from March 3, 1987, to May 31, 1989, was hindcasted using Offshore and Coastal Technologies (OCTI's) WAVAD model. This model is a second-generation, discrete-spectral wave model. Its foundations can be found in Resio (1981, 1982) and Resio and Perrie (1989). Wave data were not available for a careful calibration of the wave model; however, recent tests of WAVAD (Khandekar 1990) show that this model is capable of reproducing wave conditions quite well. Appendix C contains the time series of the wave conditions hindcast for the location shown in Figure 13.

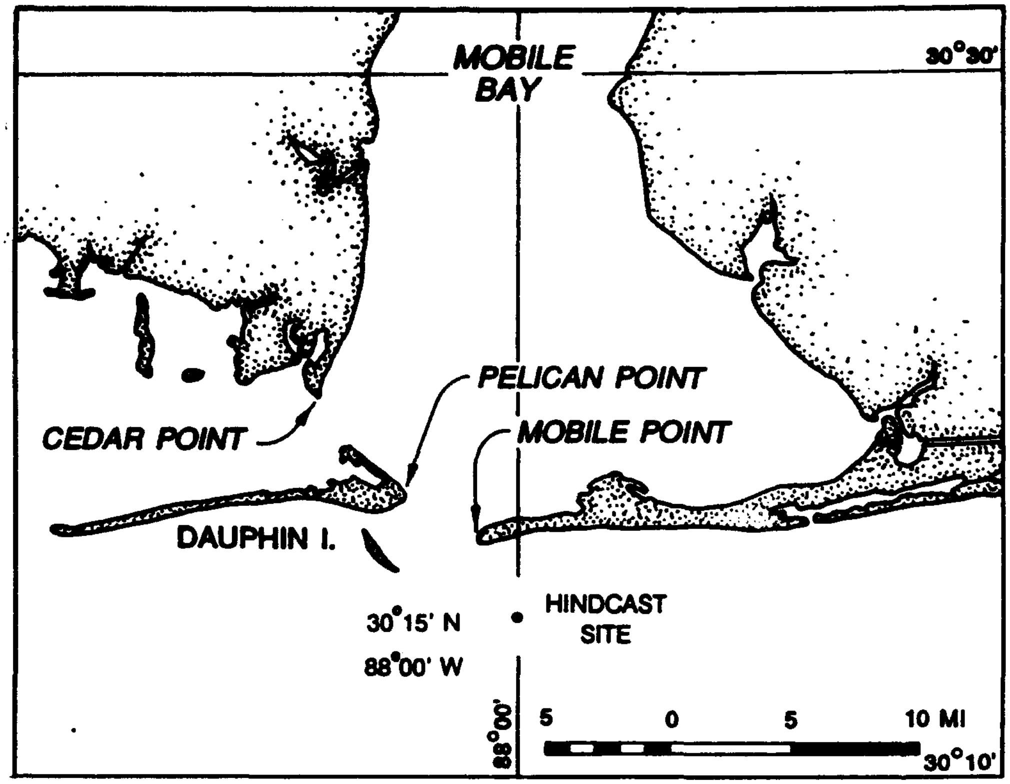


Figure 13. Location for the time series of the wave conditions hindcast

Current Estimates

The current model used for predictions of the nearshore currents was originally calibrated for the Gulf Coast area using current measurements from the study by Pickett and Burns (1988). Figure 14 shows a typical calibration result which suggests that this simple model is capable of providing a good representation of near-bottom currents in this region of the Gulf of Mexico. Appendix D contains the hindcast currents for the time interval from March 3, 1987, to May 31, 1989, for the site shown in Figure 13.

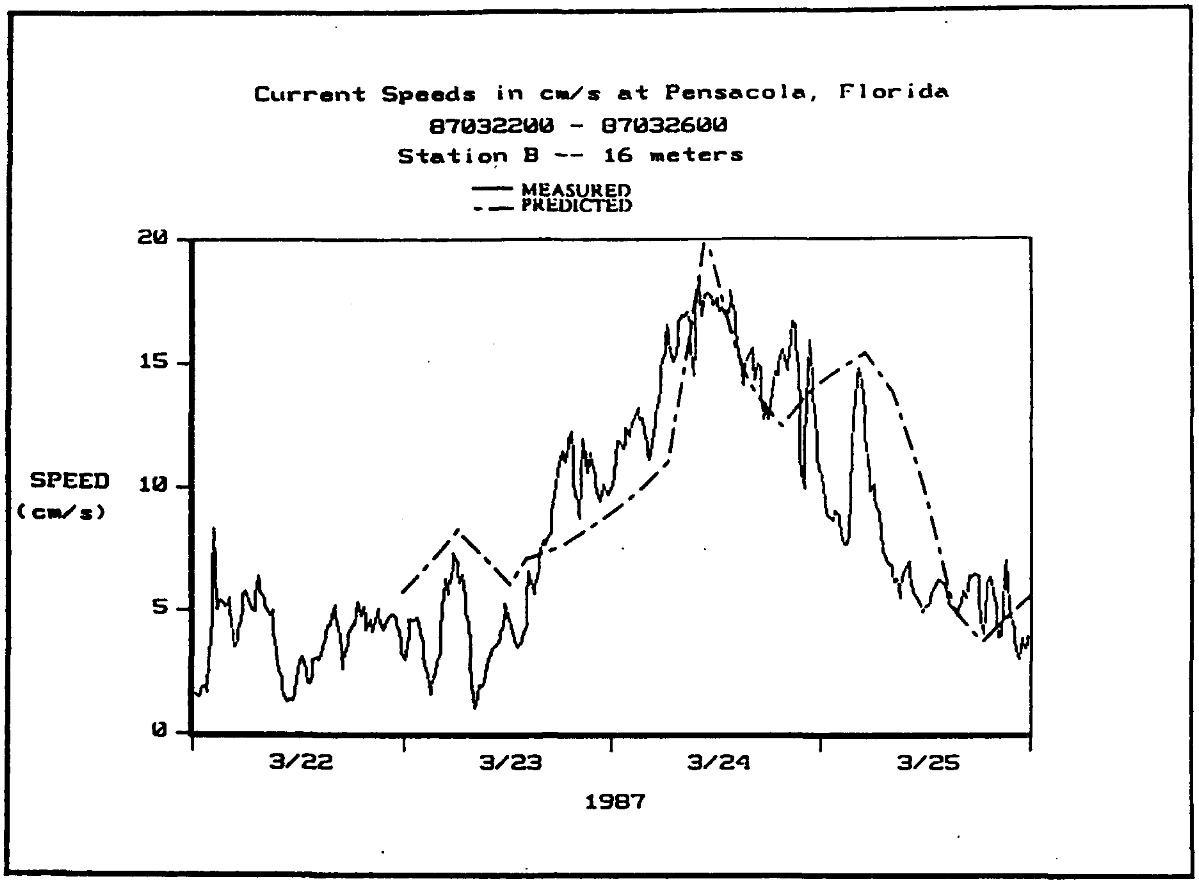


Figure 14. Comparison of measured and predicted current speeds for March 22-25, 1987, in depth of 16 m at Site B (shown in Figure 10)

4 Analysis of SBD Data

General Recovery Patterns Observed

Figure 15 gives the locations of the SBD release sites and three dredged material berms whose long-term fate is being monitored by the Corps (Hands 1992). Figures 16 and 17 show the broad-scale recovery patterns observed. In these figures, histograms of recoveries are plotted as a function of distance along the coast (i.e., number of recoveries within one-mile segments along the coast). Recoveries behind the open coast are plotted in one of two cells that coincide with the inlet through which the SBD probably entered (Hands and Bradley 1990). Figure 16 shows the recoveries stratified on the basis of release period and Figure 17 the recoveries stratified on the basis of release site.

The information in Figure 16 suggests that there can be considerable variation in recovery patterns through time. Most of the recoveries occur at locations directly onshore or west of the release sites; however, SBD's from the March 31, 1987 release and the April 15, 1987 release indicate that this pattern can reverse itself. Given the synoptic-scale variability of winds in this area, which we believe to be the major forcing function in this area, it is not surprising to see this type of variation in recovery patterns.

The information in Figure 17 suggests that the influence of the release site can be reduced to two internally homogeneous areas--an inner area encompassing release sites 1 through 4 and an outer area including sites 5 and 6. It appears that there is a tendency for the outer area to be less affected by the tidal flow into and out of Mobile Bay and, thus, to show up in less quantity inside Mobile Bay and in the Pelican Point and Mobile Point areas. This tendency is consistent with the diminishing role of tidal currents away from the entrance to Mobile Bay. Once into the general alongshore flow pattern, any other differences among the release sites are relatively small.

On each release episode except the first two (March 3 and 19, 1987) pairs of differently weighted SBD's were released simultaneously at each site. The lighter SBD's should have moved more readily when current speeds were low. If lifted off the bottom, the light type SBD would have had a slower settling velocity. Because the effect of varying SBD weights is the subject of

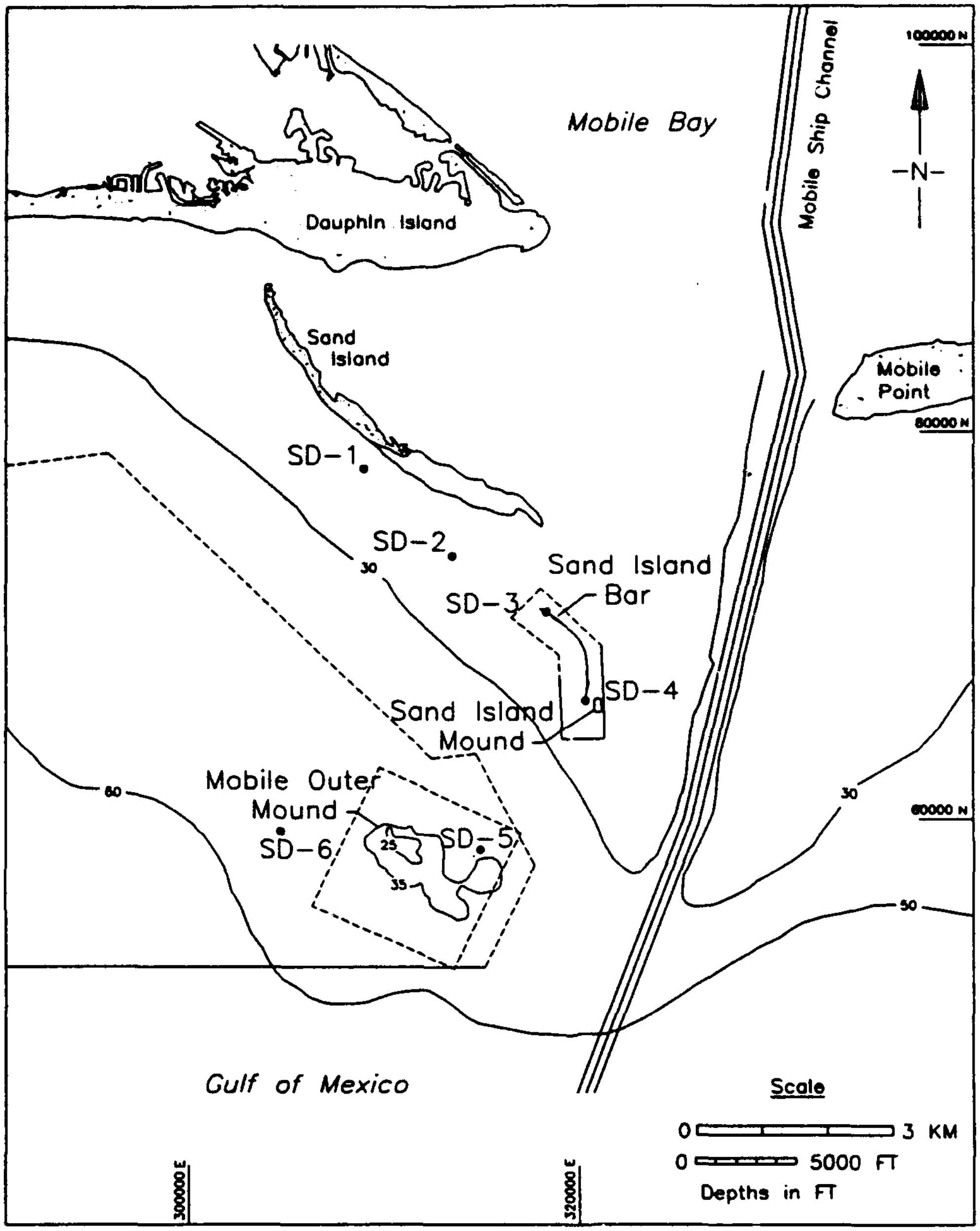


Figure 15. Seabed drifter release sites: 50 SBD's released at sites SD-1 through SD-6 during each of nine surveys

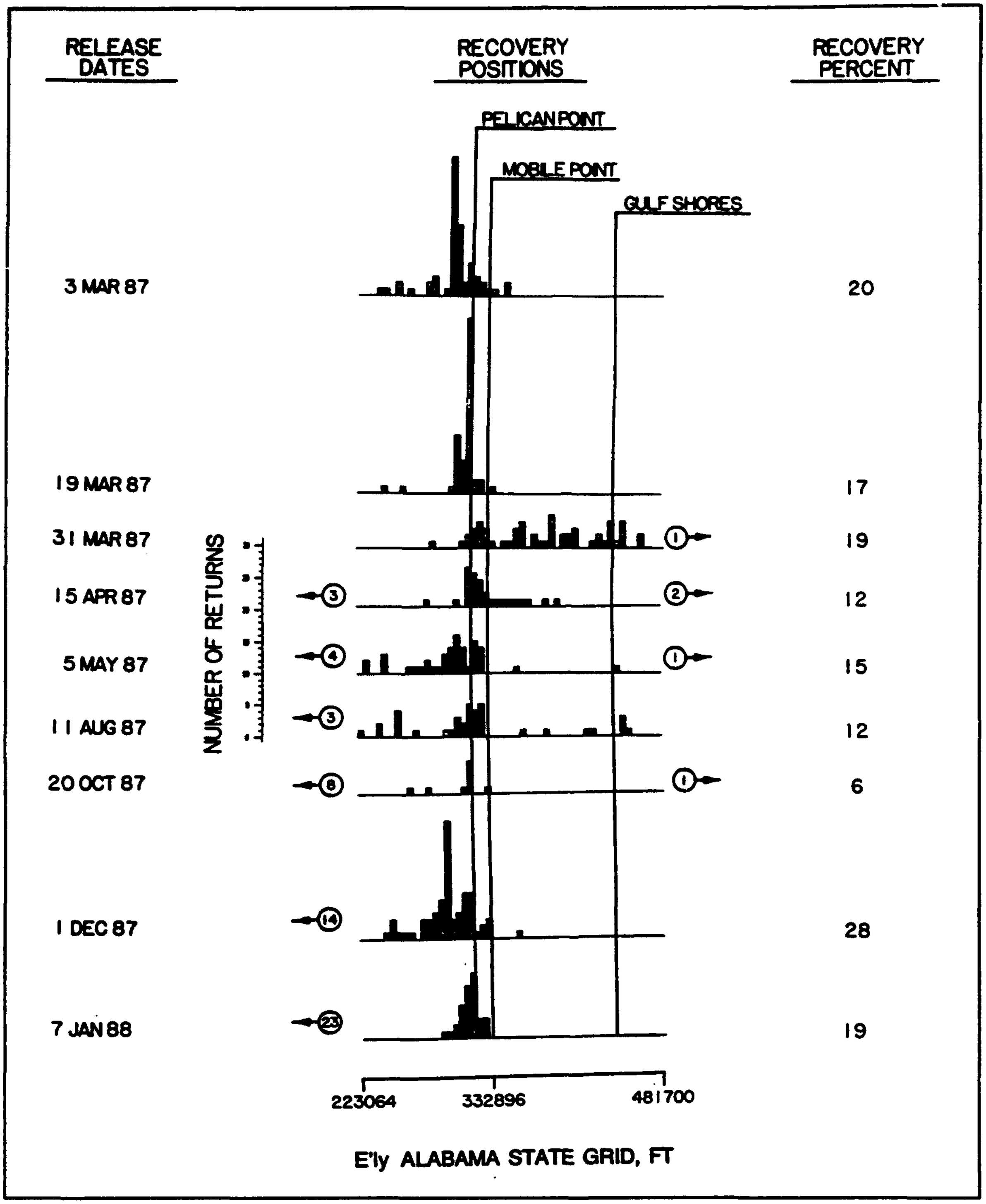


Figure 16. SBD recoveries by release periods. The highest concentration of recoveries were aligned with either the eastern or western ends of the Sand/Pelican Ridge, except after the passage of a strong cold front coinciding with the third release; in contrast, far-west recoveries rose considerably in the winter (Hands and Bradley 1990)

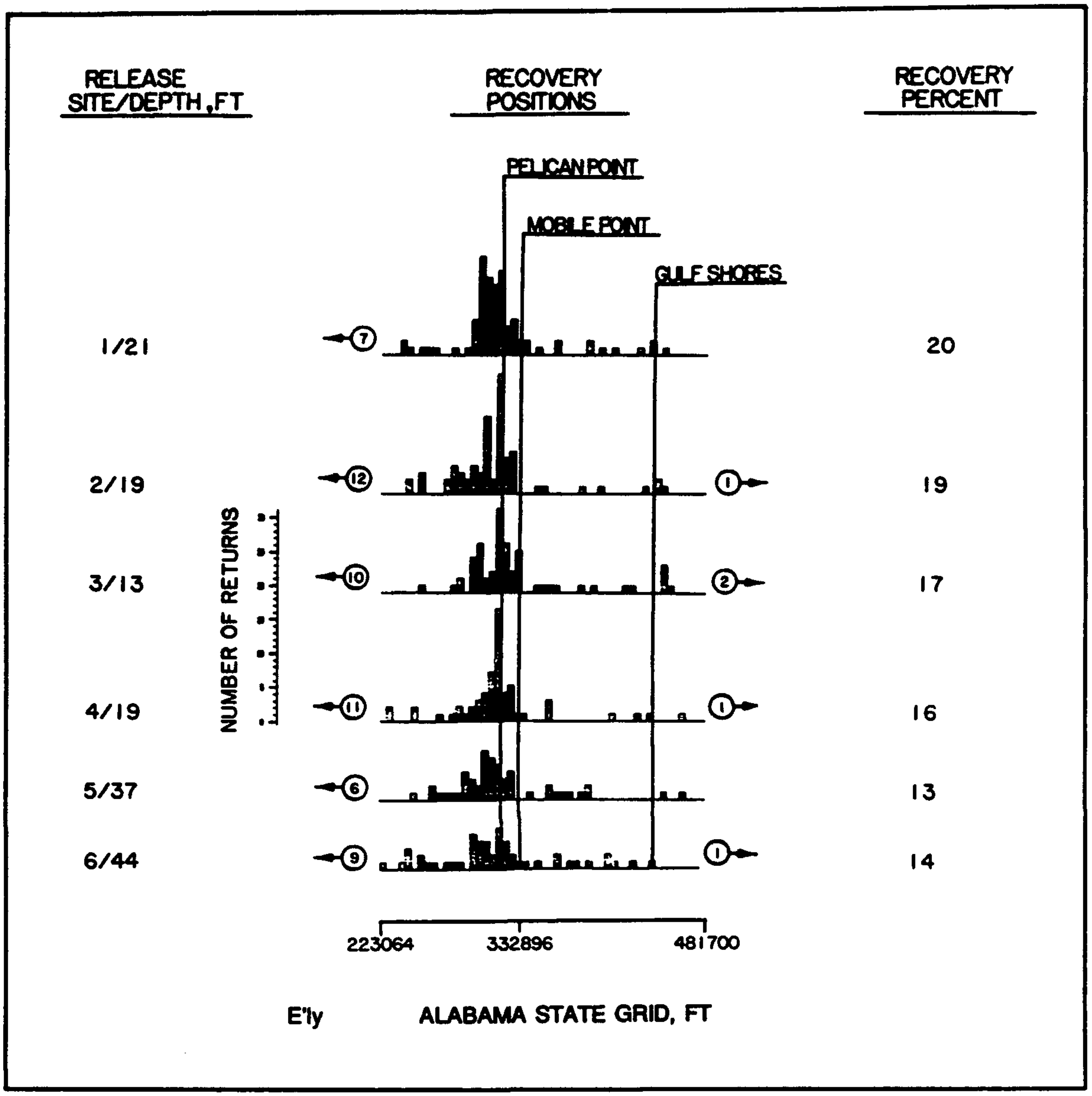


Figure 17. Distributions of SBD's from six different release sites are surprisingly similar; recoveries from the outer two sites are slightly lower in number and less focused (Hands and Bradley 1990)

a separate on-going study and the weights did not change after March 31, 1987, nor among the six sites (or in any other stratification employed here) no further distinction will be made between drifter weights in this report.

Interpreting the Percentage of SBD's Returned

In studies from around the world, the typical percent of SBD's returned has varied from 2 to 80 percent (Table 1). Figures 16 and 17 indicate that 15 to 20 percent of the SBD's released were typically recovered from the Alabama releases. By stratifying the recoveries into nearshore and offshore areas, it is possible to deduce that, of all of the SBD's returned, about 70 percent were recovered from on or near the shoreline. This observation leads one to question what mechanism is responsible for the smaller number returned from the offshore area by fishermen. Three possibilities appear to exist. First, if the SBD's drifted away from the coast into deep water, their chance of recovery would be small. Second, if they remained at about the same distance offshore as their release sites and the chance of recovery in this zone were small, their overall chance of recovery would be small. Third, if only a small proportion of the total actually recovered offshore were returned, the percentage of recognized recoveries would be low. After meetings with several state and federal officials in the Mobile Bay area and with some of the fishermen and "shrimpers" that work in this area, it seems likely that the percentage of SBD's returned from offshore is only a small fraction of those actually recovered in the nets of large offshore shrimp boats. Hence, it cannot be assumed that the natural currents move the 80 to 85 percent of the SBD's not returned into deep water or other locations where return was unlikely.

Roles of Random and Deterministic Forcing Functions

One of the most important questions concerning SBD recoveries is "How can one extract useful information from only a knowledge of the two endpoints and the elapsed time between release and recovery?" In attempting to answer this question, it is useful to separate the motions into deterministic and random components. The advantage of this distinction is apparent when the Lagrangian nature of the SBD paths is considered. A small perturbation in the position of an element of near-bottom water can lead to an ever-increasing separation from another element of near-bottom water which was not subjected to the same small perturbation. It should be noted here that these small-scale processes, which show up as randomness in the motions of the SBD's, play an important role in dispersion and the mixing processes in coastal and offshore areas. Thus, these random variations should not be simply neglected but must be filtered out, quantified, and added onto the deterministic signal when estimating the fate of materials in this environment. Some of the more important contributors to these small-scale motions are irregular wave motions, horizontal eddies in the flow field, temporary meandering currents, and rip currents in the surf zone.

If a "lump" of materials were injected into a single small region in a numerical model of currents, the materials would tend to remain rather tightly distributed in space since only the larger-scale motions are actually resolved in these models. The presence of smaller-scale perturbations must be handled via some sort of "artificial dispersion." Consequently, the resolution of the magnitude of this random dispersion could well be as important as the resolution of the deterministic component of motion in some instances. In fact, there is no a priori reason to expect that the SBD returns will definitely contain a quantifiable deterministic signal.

Before an analysis of the total data set is begun, it must be realized that many processes in nature can be obscured if they are not analyzed on the proper scale or within certain physical limits. In the case of the SBD data in the Mobile Bay area, based on our analyses of the forcing functions and scales of motion, at least three geographic regions can be envisioned where different processes might be expected to dominate:

a. The interior of Mobile Bay.

b. The entrance to Mobile Bay.

c. The open-coast region.

One important reason for stratifying the recoveries into these three regions, as will be seen subsequently, is that the analyses of processes in the interior of and entrance to Mobile Bay are both two-dimensional; whereas, the analysis of extended motions along the coast is fundamentally one-dimensional. This distinction is related to the scales of the motions as well as to differences in the relative "isotropy" of the motions in these areas (i.e., recovery position in the interior and entrance regions to Mobile Bay are not as constrained to a single east-west coordinate as are recoveries along the coast).

Inside Mobile Bay, the motions and resulting recovery patterns are expected to relate more to small-scale features such as tidal channels, shoal areas, and other such bathymetric features, as well as to recoveries by fishermen (commercial and recreational) and "shrimpers" inside the Bay. If all SBD recoveries inside a geographic region defined by state plane coordinates 200,000 to 400,000 east and greater than 93,000 north are examined, the picture of recoveries is fairly random over the western portion of the Bay (Figure 18). There were fewer returns from anywhere in the eastern part of the Bay except along a specific section of shore. These within-Bay patterns reflect returns from a highly developed residential section along the eastern shore and from the preferred shrimping areas for small boats launched primarily from the western half of the Bay.[1]

In contrast, returns from a region around the mouth of Mobile Bay (from state plane coordinates 300,000 to 340,000 east and 75,000 to 93,000 north, Figure 19) show remarkable concentrations along certain sections of the shore that probably reflect the strong influence of wave action and tidal flows with weak effects from wind-driven currents and relatively minor effects due to visitation differences.

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1 Personal Communication, December 1992, Mr. Clinton Collier, fisherman and employee at the U.S. Food and Drug Administration's Gulf Coast Seafood Laboratory, Dauphin Island, AL.

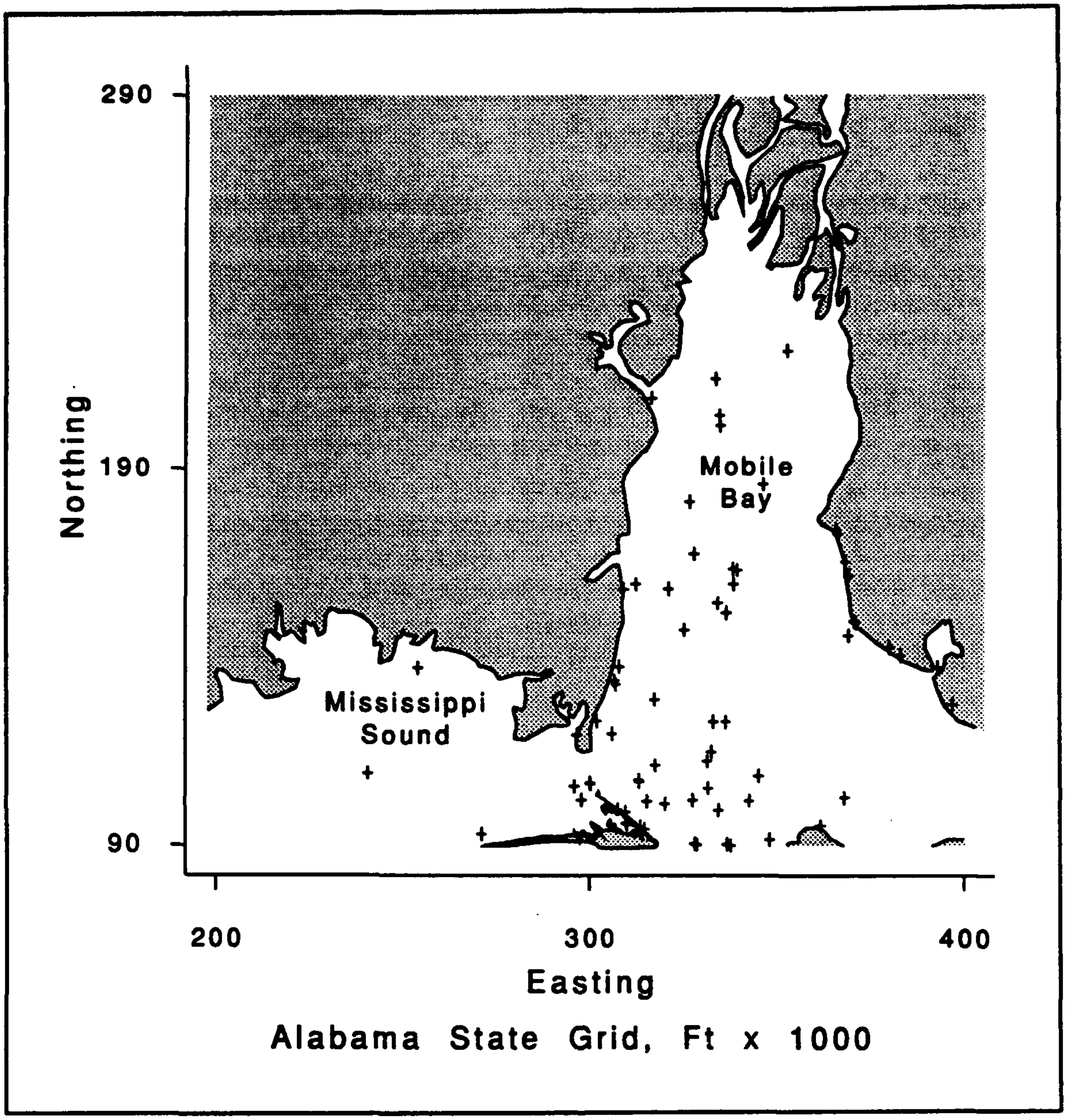

Figure 18. Recovery locations in Mobile Bay interior

If the samples from the entrance and interior of Mobile Bay are not stratified from the rest of our sample of SBD recoveries, the response of the SBD's to the wind forcing could be obscured. Given that some of the SBD's would get trapped inside this entrance and interior system of flows, they would not respond to the wind-driven currents by longshore displacement. Late recoveries in areas far removed from where the wind-driven currents had promptly taken the rest of the SBD's would also distort the direct wind effect. This distortion would show up as an increased component of randomness in the apparent motions of the SBD's.

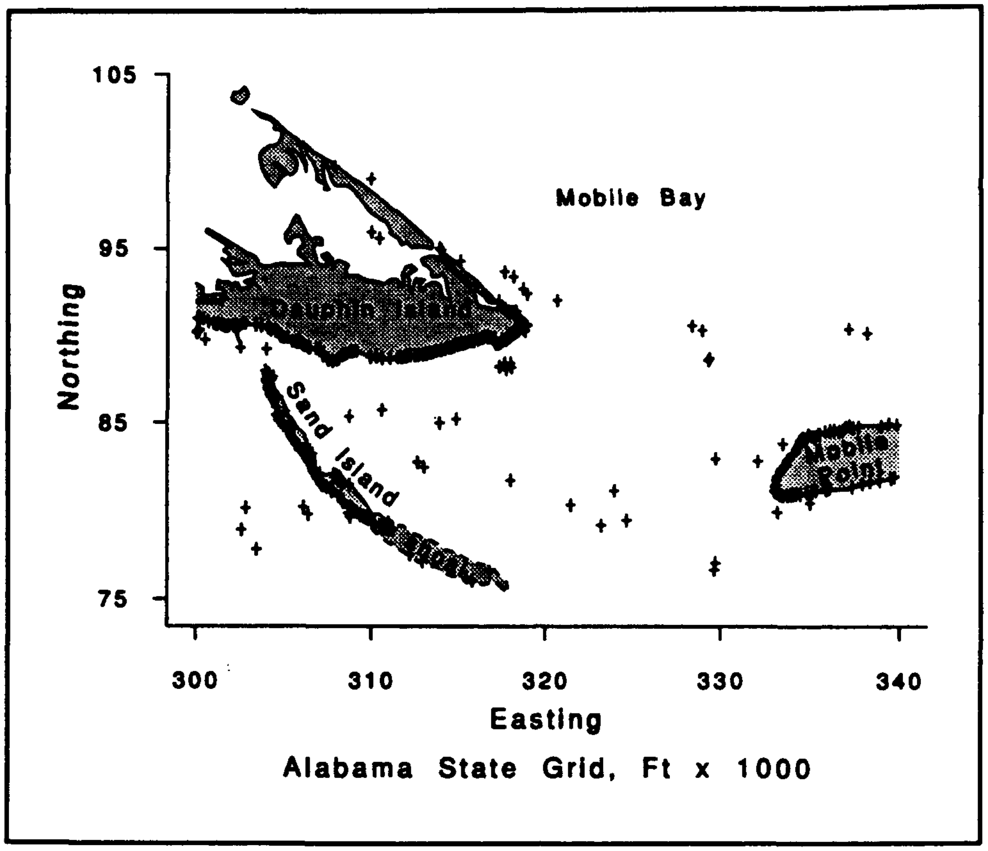

Figure 19. Recovery locations in Mobile Bay entrance regions

Table 3 gives the number of recoveries from the Bay mouth region and the interior region for each of the 19 release periods. Because a constant number of SBD's (300) were released each time, these numbers can be translated directly into percentages. Thus, the likelihood of being caught inside the Bay-entrance-interior system of flows seems quite variable. It would seem logical to expect that these differences in recoveries might relate to the phase of the tide at the time of release, with releases on flood stages being swept into the entrance-interior region more often than releases on an ebb stage. However, as shown in Figure 20, releases 1 through 6 were all made during roughly equivalent flood stages, and yet large variations in recoveries inside the entrance-interior region still exist (Hands and Bradley 1990). Possibly, it is a combination of the relative magnitudes of the wind forcing and tidal forcing over the first couple of days that determines the rate of "trapping" inside the entrance-interior region; however, the data are insufficient at present to examine this hypothesis.

As mentioned previously, unlike motions in the interior and entrance portions of Mobile Bay, motions along the open coast reflect a dominant alongshore component. Given the uncertainties in numbers and locations of shrimpers and the problem of actual recovery versus returns from offshore

Table 3
Number of SBD Recoveries

Release Episode	Bay Mouth Region	Bay Interior Region	Total
1	40	3	43
2	44	2	46
3	7	7	14
4	10	5	15
5	15	5	20
6	10	6	16
7	3	0	3
8	23	2	25
9	27	4	31
10	21	3	24
11	10	3	13
12	18	3	21
13	14	2	16
14	43	10	53
15	43	5	48
16	14	4	18
17	34	1	35
18	13	0	13
19	44	0	44

regions, it does not appear promising to undertake an analysis of the "cross-shore" distribution of recoveries. Consequently, the analysis at the open-coast scale will consider only the alongshore component of motion. Thus, the analysis of recoveries will be reduced to essentially one dimension. This allows any other independent variable (such as time) to be taken as a second dimension for plotting purposes. For the sake of simplicity of analysis and interpretation, time will be taken as the independent variable; the east-west coordinate of the recovery will be the dependent or response variable. This simplification is equivalent to projecting all of the recoveries onto a single east-west line without regard to the angle of the coast or the distance from the coast that the recovery was made. In this study such a projection still contains most of the information because most of the recovery area, once Mobile Bay is excluded, closely resembles a simple east-west shoreline (Figure 13).

In order to achieve a reasonable separation of the deterministic and random components of motion, a sufficient density of recoveries through time is needed to be able to define a broad-scale recovery function with some level of confidence. As indicated in Figure 21, the number of recoveries per day for

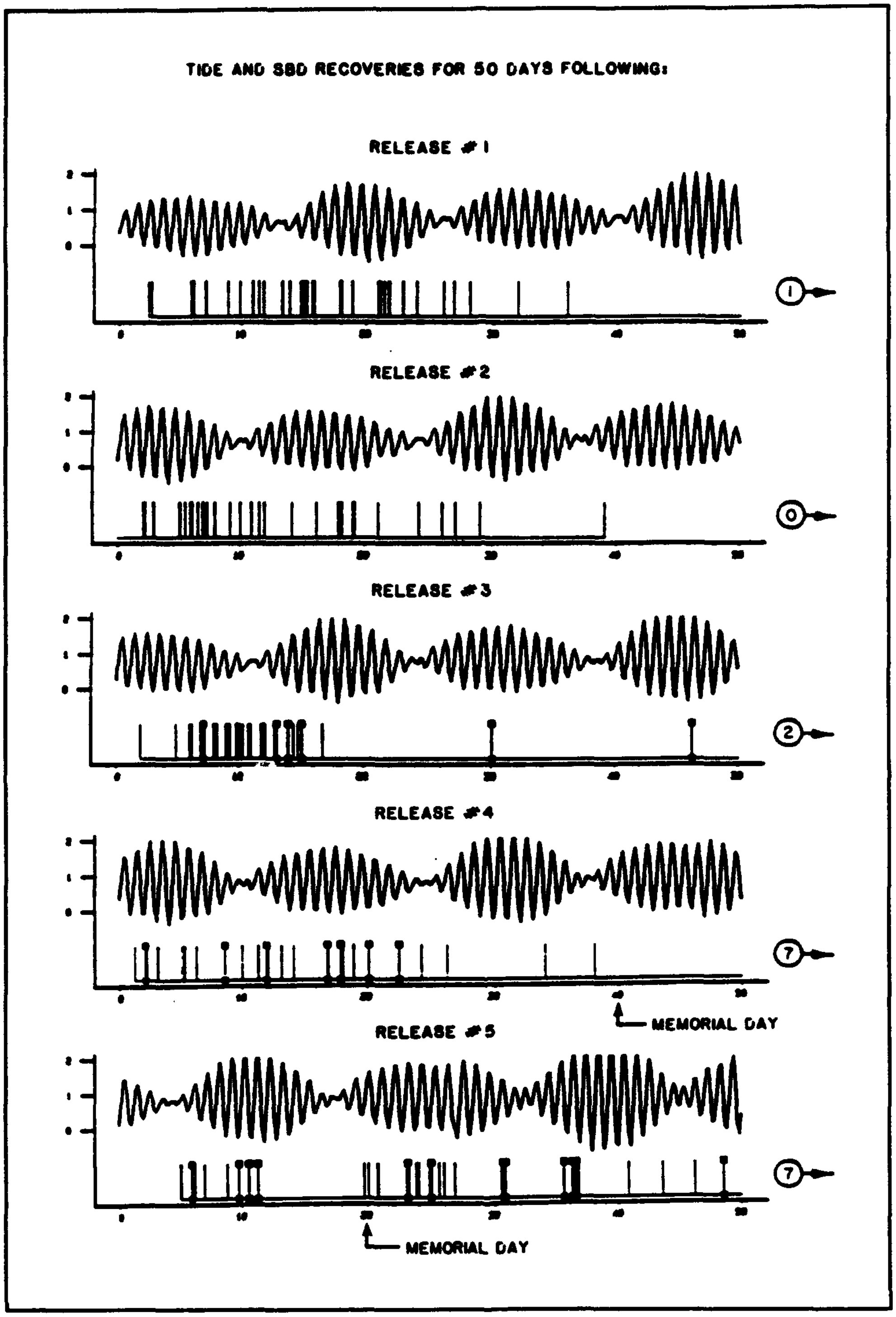

Figure 20. Tides and SBD elapse time: the spring to neap tidal cycle has no clear effect on the time of SBD recovery; the only indication of a visitation bias is a slight increase in recoveries after Memorial Day weekend; even if real, this effect would be too small to have any bearing on the overall patterns of interest in this study (Continued)

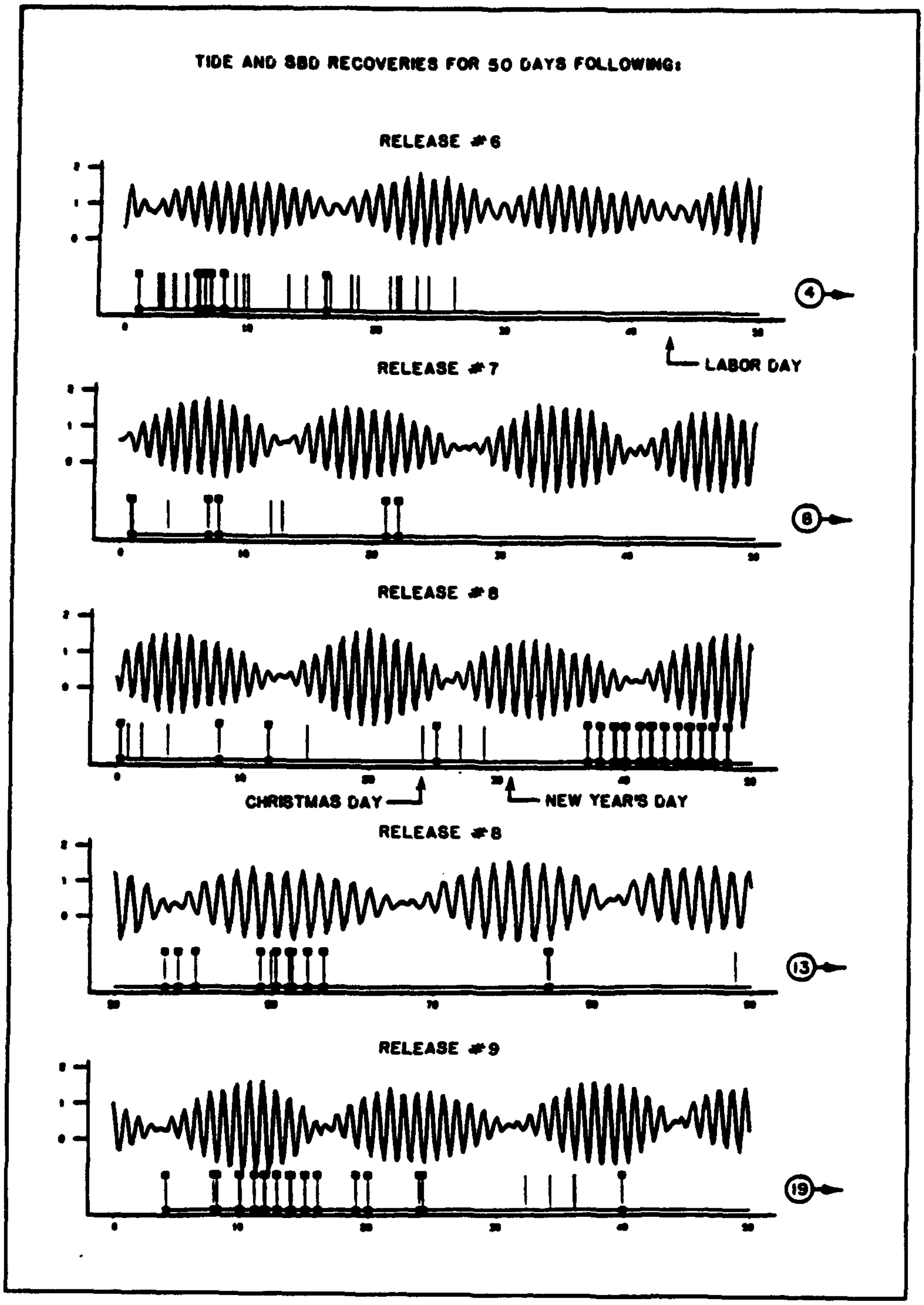

Figure 20. (Concluded)

the entire sample of SBD's tends to drop off somewhat after 15 days. Consequently, random and deterministic motions will be separated using recoveries only from the first 15 days following each release. For the purpose of this investigation, a fourth-order polynomial was selected to represent the "smooth" (i.e., deterministic) component of these recoveries. Hence, a representation of the deterministic longshore position function is

$$X(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 \tag{4}$$

where

t = time (in any units) after the release

a_0, a_1, a_2, a_3, and a_4 = regression coefficients

The parameters a_0, a_1, a_2, a_3, and a_4 are computed by a matrix "best-fit" algorithm for each separate release using the 15-day recoveries. Figures 22 and 23 show typical deterministic functions plotted with the recoveries as a function of time. Appendix E contains plots of all of the smoothed curves obtained in this fashion, along with the recovery data. As observed in Appendix E, the fourth-order polynomial fit seems to provide a good approximation in every case to what an individual might draw as a smooth "best-fit" function.

Several measures can be used to quantify the relative magnitudes of the deterministic and random components of motion. The root-mean-square (rms) deviation around the deterministic signal,

$$\sigma_x = \left[1/n \sum_{i=1}^{n} \left(X(t) - x_i \right)^2 \right]^{1/2} \tag{5}$$

where

σ_x = rms measure of the deviation

x_i = location of the ith recovery

n = number of SBD recoveries in the analysis period

will be taken as a measure of the random component of displacement. The rms deviation of the X(t) function,

$$\sigma_{x(t)} = \left[1/n \sum_{o=1}^{n} \left(X(t) - x_o \right)^2 \right]^{1/2} \tag{6}$$

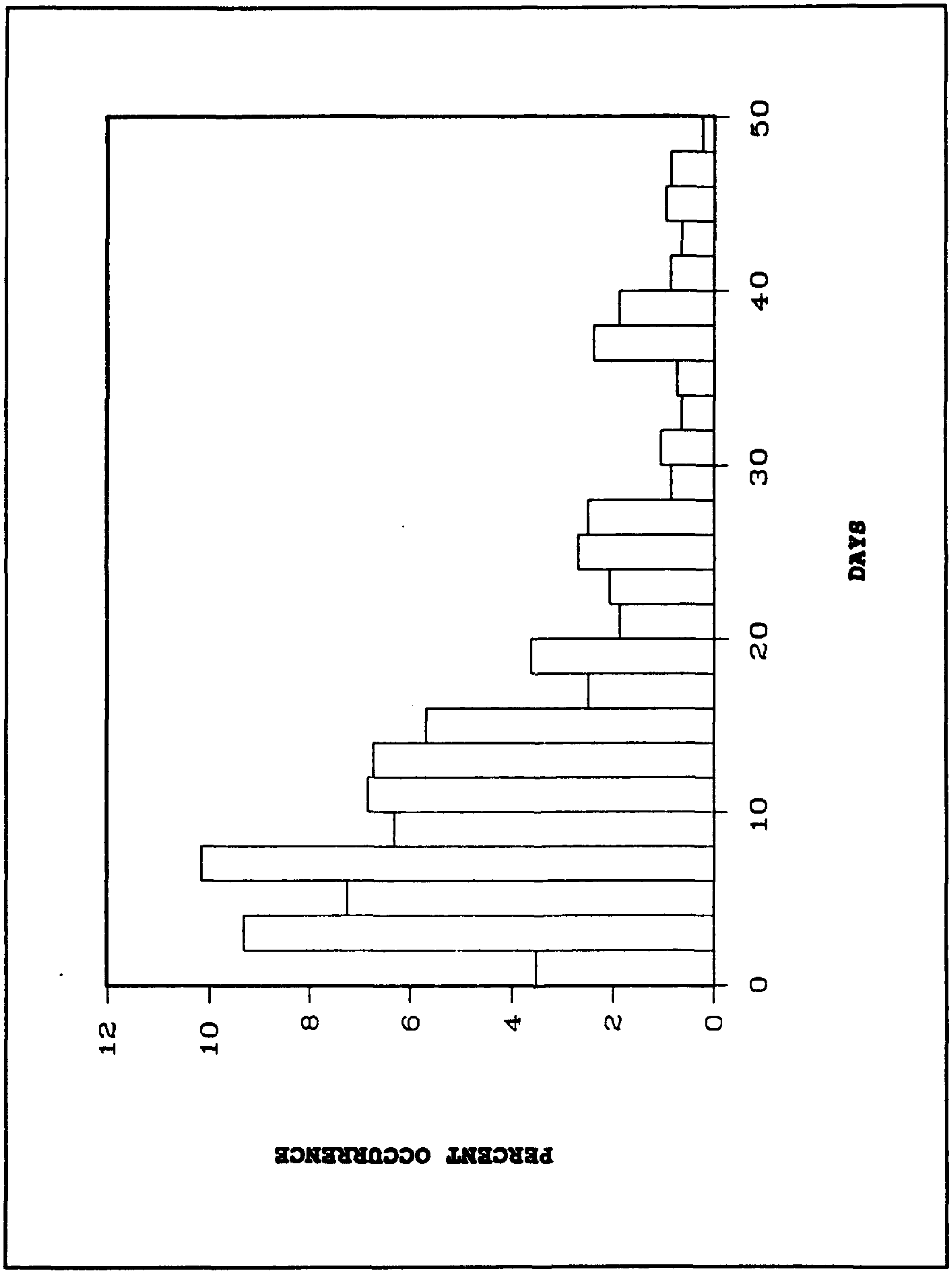

Figure 21. Histogram of times between release and recovery -- first 50 days

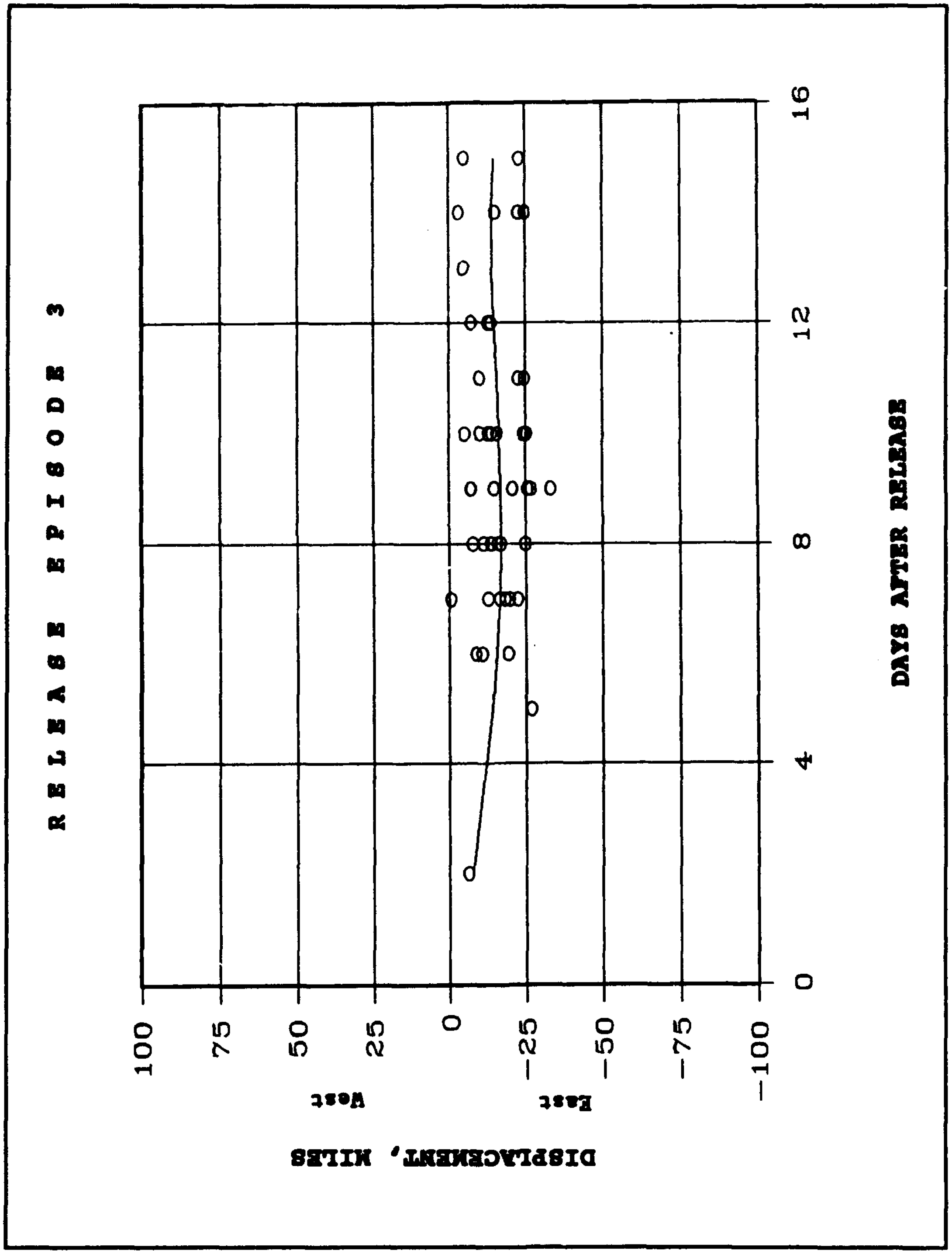

Figure 22. Fourth-order polynomial fit (—) to SBD recoveries (denoted by small circles) from first 15 days following release episode 3

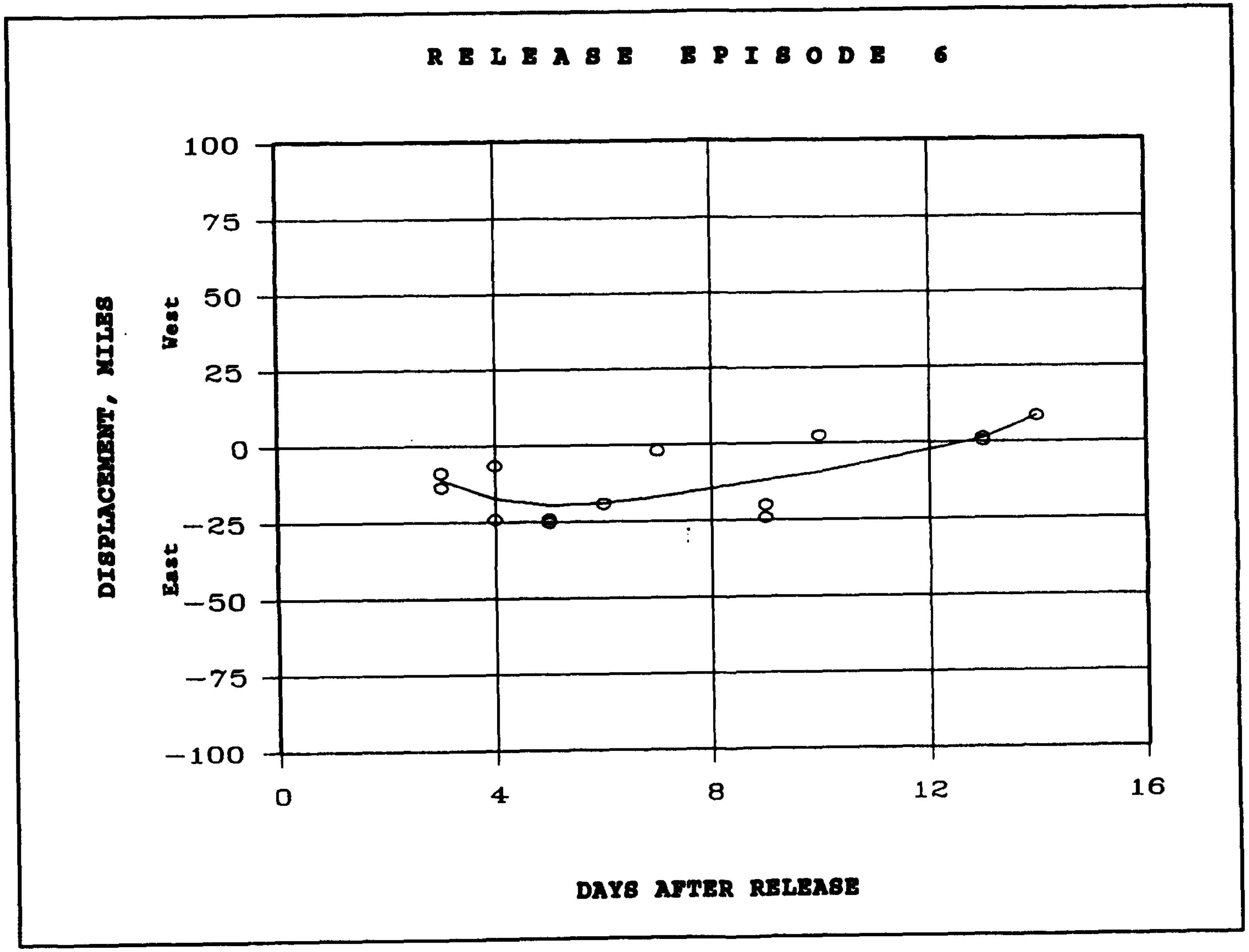

Figure 23. Fourth-order polynomial fit (—) to SBD recoveries (denoted by small circles) from first 15 days following release episode 6

where

x_0 = x-location of the release site

will be taken as the measure of the deterministic component. Then a simple measure of the relative magnitudes of the two components is

$$r = \frac{\sigma_{X(t)}}{\sigma_x} \tag{7}$$

Alternatively, the correlation coefficient, ρ , (taken here as the standard normalized inner product form) can represent the degree of agreement between the actual longshore displacement and deterministic function $X(t)$.

The central tendency of the deterministic position function can be evaluated by integrating the function over a time interval or by averaging the functional values evaluated for each recovery during that period of interest. Looking at the first 15 days after release, a mean displacement was calculated from each episode as

$$\overline{X}_{(t\leq 15)} = \frac{1}{n}\sum_{i=1}^{n} X(t_i) \tag{8}$$

where

n = number of recoveries during the first 15 days

t_i = elapsed time for the ith recovery

Table 4 presents information on all releases in which more than 10 recoveries were made in the first 15 days. A study of this table reveals that a relationship between the magnitudes of the mean displacement and the random component appears to exist. Figure 24 presents a crossplot of the relationship between the absolute value of the mean displacement and the random component. An estimate of the magnitude of the random component could be made using regression analysis,

$$\sigma_x = c_1 + c_2\,\overline{X}(t) \tag{9}$$

where

c_1 = a best-fit coefficient

c_2 = a best-fit coefficient

Table 4
Statistics of Recoveries in Open-Coast Region (First 15 Days)

Release Episode	n	ρ	r	$\bar{X}_{t\leq 15}$	σ_x
1	18	0.85	1.6	0.0	1.1
2	21	0.55	0.8	0.8	2.8
3	46	0.20	2.5	-15.8	7.6
4	11	0.81	3.2	-14.3	8.2
6	14	0.74	2.2	-11.1	7.7
10	19	0.34	3.4	- 5.9	2.3
11	23	0.98	10.6	-18.0	3.1
12	18	0.72	1.8	3.8	2.9
13	13	0.99	5.4	11.2	0.4
14	28	0.61	5.1	1.3	0.4
15	40	0.47	1.0	1.6	3.2
17	29	0.58	1.1	2.1	7.8
18	84	0.60	1.9	-36.1	22.2
19	74	0.42	2.2	-17.2	14.3

Key:
n = number of recoveries in first 15 days
ρ = correlation coefficient between the deterministic function, $X_{(t)}$, and the actual data
r = ratio of deterministic to random signals
$\bar{X}_{t\leq 15}$ = mean displacement, miles
σ_x = rms of random signal, miles

Another facet of Table 4 that is interesting is the apparent relationship between the ratio of the magnitudes of the deterministic and random components of motion, r, and the mean displacement $\bar{X}_{t\leq 15}$. This relationship expresses a tendency for the relative importance of smaller-scale motions to diminish when strong net transport occurs over the whole study area.

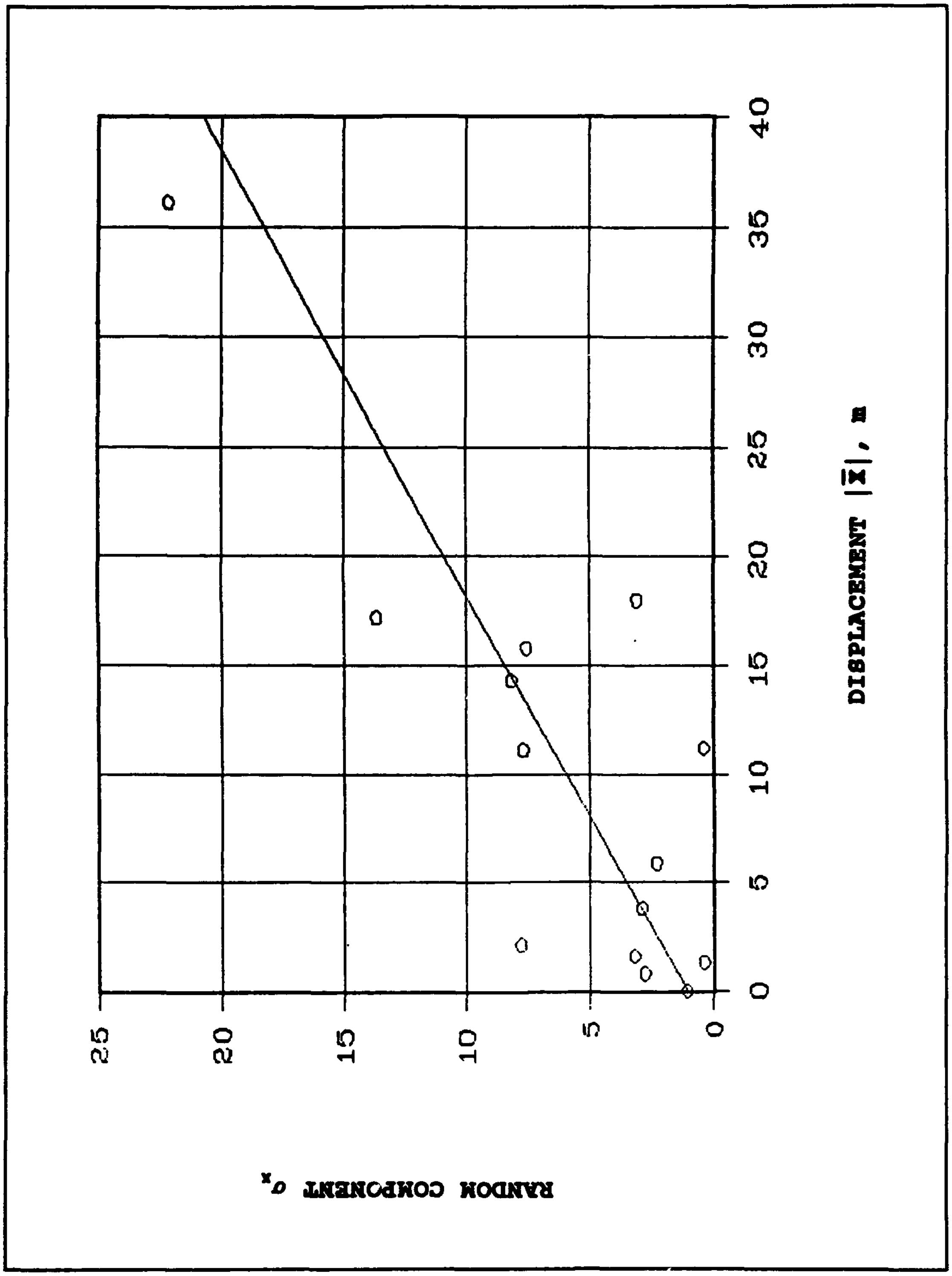

Figure 24. RMS error versus displacement

5 Comparison of SBD Patterns to Physical Processes

Mobile Bay Data Set

The patterns of the "deterministic" function (shown in Appendix E) indicate that there are distinct differences among the processes affecting the SBD's during the intervals following different releases. An examination of weather maps for the periods following each release shows that the synoptic weather patterns are highly variable, with the major wind forcing linked to the passage of warm and cold fronts. Two strong frontal passages were identified in this review, one following Release 2 and the other following Release 3. Recall that Release 3 resulted in the unusual eastward movement of SBD's shown in Figure 16. If daily weather maps (0000Z maptimes) for the 15 days following Release 2 (March 19, 1987) are compared with weather maps for the 15 days following Release 3 (March 31, 1987), the alongshore component of wind in the latter case will be markedly affected by a cold front passing through the release area on March 31 and another on April 3. In contrast, the overall winds were quite small following Release 2 even when a weak cold front passed through on March 25. The reversal of flow back to the east may have been a response to the strong west winds following the March 31 frontal passage, and thus would be more likely to occur again during the winter when such fronts are most common.

In order to investigate the relative roles of wind-driven currents and waves, it is advantageous to be able to obtain parameterized estimates of the potential strength of these two processes and to compare these estimates to the observed recovery patterns. Because the scale of the recoveries is on the order of days and there is not much information on the exact SBD paths, some sort of time averaging is helpful. Appendix F contains a set of categorized plots for all releases. In these plots, wave and current processes are categorized as indicated in Table 5 for three successive 5-day intervals after each release date. From this data presentation, a definite picture of the relationship between the forcing processes and the SBD response begins to emerge.

Table 5
Definition of Wind and Wave (5-Day Categories)

Wind Category	Wind Speed
0	$U_{42'} < 10$ knots
1	10 knots $\leq U_{42'} < 20$ knots
2	20 knots $\leq U_{42'}$
Wave Category	**Wave-Driven Current Speed**
0	$\lvert\bar{V}\rvert < 15$ cm/sec
1	15 cm/sec $\leq \lvert\bar{V}\rvert < 30$ cm/sec
2	30 cm/sec $\leq \lvert\bar{V}\rvert$

Because of the high degree of variability in our system (in part due to the Lagrangian nature of the SBD recoveries and to the importance of subscale processes influencing the total path) and the parameterization of the processes, methods for calculating relationships between continuous variables are not well suited to analysis of these results. On the other hand, a contingency table analysis is an excellent tool to clarify the interrelationship between estimated wind and wave forcings and the SBD responses. Consequently, contingency tables will be used here in place of correlation coefficients, rms errors, biases, or other such measures to investigate the statistical strength of the relationship of SBD displacement to winds and waves. Tables 6 and 7 present contingency tables constructed from the joint occurrences of observed and predicted categorized motions using the definitions given below:

a. Observed variations of X(t) were categorized into 5-day values of -1, 0, and +1 depending on the maximum deviation between the X(t) in that 5-day period and the previous 5-day period. If the maximum deviation was greater than 10 miles and with the later value westward of the earlier value (i.e. the motion is westward), the value was taken as -1. If the maximum deviation was greater than 10 miles toward the east, the value was taken as +1; if the maximum deviation was less than 10 miles, the value was taken as 0.

b. If the parameterized 5-day value for wind-driven currents was 0, the contingency table classification became 0. If the wind category was greater than 0 (i.e., a 1 or a 2 value from our categorization shown in Table 5), it was assigned a value of -1 if the predicted displacement was toward the west and +1 if the predicted displacement was toward the east.

Table 6
Contingency Table for All Release Episodes for Wind-Driven Currents

Predicted Category	Observed Category -1	0	1	Marginal Total
To W -1	3	2	0	5
0	2	33	0	35
To E 1	0	4	10	14
Marginal Total	5	39	10	

Table 7
Contingency Table for All Release Episodes for Wave-Driven Currents

Predicted Category	Observed Category -1	0	1	Marginal Total
To W -1	6	15	4	25
0	1	20	4	25
To E 1	0	0	4	4
Marginal Total	7	35	12	

c. If the parameterized 5-day value for waves is 0, its contingency value was taken as 0. If it was greater than 0, its value became -1 if the predicted motion was toward the west and +1 if the predicted motion was toward the east.

Tables 6 and 7 help to summarize the degree of agreement between these parameterized processes and the SBD responses. As can be seen in Table 6, there is good agreement between the categorized wind-driven currents and the SBD responses, as evidenced by the prevalence of occurrences along the diagonal. On the other hand, the wave processes predict wave transports toward the west much more often than the SBD's actually moved to the west.

A second pattern that emerges from the plots of the data in Appendix F is the relatively large number of apparent outliers that end up far to the west of the release sites, even when the wind-current forcing does not seem to support such movement. One possible interpretation of this pattern is that a secondary circulation pattern inside and along the Mississippi Sound region may operate predominantly from east to west.

An alternate explanation for the extreme western recoveries that were not wind-related is that SBDs could have moved westward under the influence of wave-driven currents yet not have been credited to that category because those SBDs did not move sufficiently shoreward to the beach where any further movement would have been interrupted and the chance of recovery would have increased. Upon completion of the continuing release episodes, reanalysis of the analytic data may resolve this question of relative wind and wave effects. For now, this example illustrates the methodology and the usefulness of parameterizing, sometimes opposing transport functions and appraising their joint influence via contingency tables.

General Interpretation of SBD Results

From an analysis of the potential driving mechanisms for SBD motions, it appears likely that in open-coast areas direct wind and secondary wave forcing are the dominant factors to consider in the interpretation of SBD recovery patterns. Near inlets, tidal currents are important. In areas immediately adjacent to large partially-mixed or mixed estuaries, two-layer flow systems may become dominant as seen in the study by Pape and Garvine (1982). However, inside the Gulf of Mexico and major coastal sections of the Atlantic and Pacific seaboard, the inner shelf circulation will most likely respond primarily to direct wind forcing in the region from the shore out to depths of 40 m or so. Beyond these depths, additional effects such as large-scale circulations and layered flow regimes can become dominant. It is, however, in coastal water that sediment transport, the fate of dredged materials, and the dispersal of dissolved pollutants are of major concern. Because interest is often properly focused on coastal waters, the importance of the offcoast considerations may, in fact, be minimal.

After an examination is made of how the results of various analysis procedures apply to the Alabama Coast, the procedures should be tested on data from other sites. Hands (1987) discusses a series of SBD releases made along the North Carolina coast near the U.S. Army Coastal Engineering Research Center's (CERC) Field Research Facility. Repeated releases were made from two nearshore sites on each of four days. The SBD's from releases made on the first three days promptly came ashore a little north of their respective release sites (Hands 1987). About 80 percent consistently appeared ashore about 6 hr after their releases in depths of 8 m. On the morning of the fourth release, just as these SBD's began to appear on the beach, a "northeaster" with winds in the range of 25 to 30 knots began affecting the study area. During the next six days, winds remained primarily out of the northeast. From the analysis of wind-driven currents presented earlier and consistent with Murray's (1975) analytical model, the near-bottom currents during this period should have been approximately alongshore, with a small component in the offshore direction. Hence, few SBD's should have been forced to the shore, independent of the wave conditions. This inference is consistent with the actual observations by Hands (1987) who reported "as the wind veered to the northeast, the SBD's abruptly stopped coming ashore." In fact, over the next 48 hr (in which the winds remained strong from the northeast), he wrote "in spite of vigilant searches..., no more drifters were recovered." From this information and the fact that during the previous period of seaward-directed winds the SBD's from repeated releases drifted ashore after brief and consistent transit times and in high percentages, it appears that the local winds play a important role in determining whether or not SBD's return to shore. Thus, the cross-shore component of the wind significantly impacts the probability of recovery.

Next, details of the Duck data set are examined to see if the observed long-shore SBD displacements are reasonably consistent with the simple parametric wind-driven current model. Figure 7 gives a graphical presentation of this parameterization. In the Duck data set, the first recoveries following onset of the northeaster (September 11) occurred during the period of September 20 to 23. Over the intervening 9 to 13 days, the winds averaged about 6.5 m/sec. The angle of the wind to the coastline was about 70 deg during this time. Figure 7 suggests a mean current of approximately 15 cm/sec. Of course, the currents would have been much higher during the short September 11 to 13 interval. Ten days of drifting at an average 15 cm/sec would place the SBD's about 130 km south of the release site. Because recoveries occurred from 55 to 103 km to the south, the 130-km estimate agrees well with the observed displacements. In fact, given the large number of subscale effects and the unknown elapsed time between beaching and recovery, the timing of actual SBD recoveries is probably as good a confirmation as could be expected even if the parameterization of the currents had been perfect.

The examination of this ancillary data set shows that the methodology developed for the Mobile Bay area can be generalized to other comparable open-coast areas. Because the theoretical basis for the parametric wind-forcing estimates given here is appropriate for near-bottom water elements, it can be reasonably assumed that nearly neutrally buoyant SBD's respond to wind forcing in a fashion similar to elements of water in the near-bottom water column. This assumption is excellent if a study is seeking to gain information on the general water circulation or on materials which should move in suspension (pollutants, contaminants, etc.). However, it means that as presently configured, SBD's probably do not provide direct evidence on the fate of materials that move along, or only infrequently off, the bottom (dredged, bypassed, or beach-fill material, coarse natural sediments, etc.). As might be inferred from the treatment of differences between forces acting on the SBD's and a sand particle in Chapter 3, a redesign of the SBD's, reducing the large plastic cap or increasing the resistance to displacement, might be good starting points to begin making the SBD's become more direct predictors of bottom materials.

Given the results of all of the theoretical and empirical analyses, several general conclusions regarding the interpretation of SBD recoveries may be drawn.

a. In their present design, SBD's apparently respond in a manner consistent with the motions of near-bottom water. Any inferences as to related motions of bottom sediments or materials placed on the bottom must be carefully considered and tested before they should be accepted.

b. In the interpretation of SBD motions it is helpful to analyze all potential driving motions, perform a scale analysis, and ensure that any interpretation of recovery patterns is consistent with these physical processes. This methodology will allow the separation of different scales of motion and resulting patterns that should suggest appropriate approaches (sample stratification, temporal smoothing, etc.) for analyzing the recovery data.

c. In open-coast areas outside the breaker zone, the single most dominant process influencing motions of conventionally ballasted SBD's usually seems to be the wind-driven currents. A simple parametric approach to estimating near-coast currents can be valuable in interpreting the expected scale of motions due to this process and hence can aid in experimental design and overall SBD deployment considerations.

d. Inside the breaker zone, wave forcing becomes the dominant process. Wave-driven longshore currents in the surf zone should control many important convergence and divergence aspects of material fluxes. Areas of convergence should coincide with deposition of materials (i.e., a local concentration of SBD returns as on Pelican and Mobile Points). Areas of divergence should be reflected by a lower concentration of SBD returns (as seen along the shoreline embayment in the lee of Sand Island). However, the scale of the wave-driven motions affecting the SBD recovery patterns inside the breaker zone should only be considered as a process with a scale of tenths of miles or at most miles, not 10's of miles as is the case of direct wind-driven current.

e. Near mouths of inlets, embayments, estuaries, and rivers the tides and riverflows can become a dominant process and should be considered in interpreting SBD recovery patterns.

6 Conclusions and Recommendations

Conclusions

The following conclusions are made:

a. Attempts to interpret SBD patterns should begin with an analysis of the physical processes in the area of interest. Evaluation of the dominant processes will help develop the appropriate analysis for each situation.

b. In open-coast areas, wind-driven currents are usually the primary forcing process for SBD's. Because winds in coastal areas vary as a result of mesoscale effects (sea-breeze/land-breeze, etc.) and synoptic-scale effects (storms, fronts, etc.), the response of SBD's can be variable, depending on the conditions prevailing during the period following their release. Consequently, care should be taken to accumulate data from as many releases as feasible. The number necessary will increase with the variability of the driving forces, the scales and periods of interest, and the purpose of the study. The recovery pattern from a single release should be interpreted as a single, possibly representative case. A more typical study would include a dozen or more release episodes covering different conditions throughout the year. In areas where winds are variable (almost every coastal area), the climatology of all patterns from many returns should be considered in interpreting the climatology of circulation patterns. In areas such as the Mobile Bay region and North Carolina coast, the expected transports during a given synoptic event (such as a frontal passage or storm) can produce motions on the scale of 100 km in a time span of only two to three days.

c. The probability that a SBD will be found can vary with the location and time of year when it reaches shore. The chance that a recovered drifter will be returned can also depend on who finds it, when, and where. These site-sensitive uncertainties should be considered when interpreting the recovery patterns. For recoveries within Mobile Bay, the returns reflect differences in shrimping by numerous small boats. For offshore recoveries, the likelihood of recovered SBDs being returned appears to have been diminished if the SBDs were recovered by commercial fishermen and shrimpers in the course of their trawling activities.

d. Information from SBD recoveries contains both deterministic and random components. Normally, information is only available on the starting point, end point, and elapsed time, so caution should be taken in attempting to explain every recovery site in terms of a single deterministic process. The relative importance of random and deterministic components varies greatly among different release episodes. Sometimes SBD's can be recovered tens of miles apart on the same day following their release at the same time from the same location. Usually, this divergence should be interpreted as indicating the existence of important random motions or a secondary circulation pattern (such as possibly occurs in the western portion of the Mobile Bay study area). At other times, when there is a strong uniform response, the deterministic component predominates.

e. Combining SBDs with current meter measurements and modelling provides more complete and useful documentation of large-scale current patterns than possible using either method alone. Consideration should be given to pilot SBD releases that would establish likely number of returns and indicate the spatial variability before selecting the number and location for instrument measurements. Because of their relatively low cost, SBD drifter releases can not only cover a wider area but also continue over a longer period than usually feasible using other methods.

f. Data from SBD recoveries can provide valuable information on the potential motions of suspended materials in near-bottom waters. Such information could be vital to improved understanding of the fate of materials released at outfalls, with toxic wastes, spills of hazardous materials, medical wastes, and any other such material that might become suspended in the water column. Some of this information needs to be recognized in terms of its dependence on seasonal and synoptic weather patterns and then could be used to minimize potential environmental hazards by improved scheduling of outfall flows, offshore operations related to oil and gas production, shipping, and any other such potentially hazardous offshore activities.

Recommendations for Future Work

Because of the potential value of SBD data, the following recommendations are made:

a. SBD experiments should be conducted as a supplement to all ongoing monitoring programs. Whereas in situ velocity measurements are useful for some purposes, SBD data can provide a much more direct source of information on the potential fate of suspended materials.

b. A redesign of the SBD's should be considered in order to allow the SBD's to be more characteristic of bottom (infrequently suspended) materials. Such a redesign might begin with reduction, lowering, or removal of the plastic caps in the present design. It should be noted that the modified SBD's might not move as far; consequently, a greater number of SBD's per release bundle and a longer and more intensive sampling procedure would be required.

c. Metal ferrules crimped on the ends of SBD stems overcome the buoyancy of the plastic components and, in typical deployments, render the assembled SBD's nearly neutrally buoyant. Further increasing the ferrule weight should increase the SBD's resistance to displacement. As a step toward increasing the usefulness of SBD's for inferring the fate of infrequently suspended particles, laboratory investigations are being conducted to determine the feasibility and procedure for increasing the SBD's threshold for movement until it approximates that of the material whose fate is of concern (Hands and Solitt, in preparation).

d. Successful methods to mimic threshold conditions might be followed by investigations into the differences in velocities of the SBD's and of the sediment particles. As this report has shown, velocity differences should be expected and divergences in displacement will tend to increase with the elapsed time between release and recovery. Because scales of mixing and turbulence vary temporally, spatially, and with changes in flow intensity in manners that are poorly known, clarifying velocity relationships will probably require considerable laboratory and field testing.

e. The extra effort of detailed tracking of transmitter-attached SBD's via sonic methods (Dickson 1976; Folger 1971; Harden Jones, Greer Walker, and Arnold 1973) would be especially useful with the modified, more sediment-like, SBD's. This would increase the need for additional refinements in sonic tracking techniques.

f. Given the potential value of SBD studies compared to their relatively inexpensive cost, additional research should continue into future improvements in interpretation and experimental design.

g. In sites such as the Mobile Bay area where a good data set already exists and where long-term measurement of waves, winds, and bottom currents is underway, releases should continue for several years in order to begin to develop improved quantitative methods for estimating overall climatological parameters for the potential motions. Such information would also be valuable for determining the number of releases that are required to obtain a reasonable estimate of the entire climatology.

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Appendix A
Rationale for Equations Used to Estimate Wave-Driven Effects

Equation 1 represents a simplification of the combined effects of the following processes responsible for the generation of longshore currents in open-coast areas:

a. Deepwater wave generation.

b. Wave transformations from deep water to the surf zone.

c. Transfer of momentum from the wave field into mean currents within the surf zone.

Locally generated deepwater wave heights depend on not only wind speed but also stage of development. As an asymptotic, fully-developed limit, such wave heights depend on wind speed squared (Pierson and Moskowitz 1964).[1] Before this limit is reached, wave heights are controlled by either duration or fetch. If waves are fetch limited, wave heights depend on the square root of the fetch and on wind speed to the first power (Hasselmann et al. 1973). If waves are duration limited, wave heights vary with duration to the $5/7^{th}$ power and with wind speed to the $4/3^{rd}$ power (Resio 1981). Thus, given that storms of similar size and duration characteristics are repeated from year to year, the deepwater wave heights, H_0 , could be expected to vary as U^p where p lies in the range $1 < p < 2$.

The transformation of wave heights from deep water into the surf zone will depend on conservative (refraction, shoaling, diffraction) processes and nonconservative processes (wave breaking, nonlinear wave-wave interactions, bottom friction, etc.). In general, these processes cannot be represented as simple power laws of wave height; however, as a climatological average, it can be assumed here that nearshore wave heights tend to vary approximately

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1 References cited in this appendix are located at the end of the main text.

linearly with deepwater wave heights. Complete calculations of wave transformations indicate that this assumption is reasonably consistent with transformations observed in nature (Resio 1987, 1988). Hence, $H_b \sim H_o$, where H_b is the wave height at the edge of the surf zone.

The momentum flux into the surf zone per unit width can be approximated as

$$M_{in} = C_g \cos(\theta) \frac{H^2 \sin(\theta)}{c} = nH^2 \cos(\theta) \sin(\theta)$$

where

c = phase speed

C_g = group speed

The rate of transfer of this momentum per unit area into currents scales as

$$\tau_{in} \sim nH^2 \cos\theta \sin\theta / w$$

where

w = surf zone width

The rate of loss of momentum per unit area is given by

$$\tau_{out} \sim C_D \frac{U^2}{g}$$

which will form a balance with the input when

$$U^2 \sim H_b \phi_1(\theta)$$

Substituting this relationship into the relationships given in the two previous paragraphs recovers Equation 1.

Appendix B
Notation

A	Cross-sectional area
A_r	Cross-sectional area along the circumference of a circle with radius r
c	Phase speed
c_1	Best-fit coefficient
c_2	Best-fit coefficient
C_g	Group speed
g	Acceleration due to gravity
H_b	Breaker height
K_1	This constituent, with 0_1, expresses the effect of the moon's eclination and accounts for the diurnal inequality of the tides
m	Beach slope
n	Number of recoveries during the first 15 days, or number of samples
p	Exponent dependent on sea state, but close to 2 for fully developed waves
q	Exponent approximately equal to 1
Q	Volume transport rate
r	Ratio of deterministic to random signals
t	Time (in any units) after the release
t_i	Elapsed time between release and the *i*th SBD recovery
U	Windspeed
V_{waves}	Speed of longshore flow outside the surf zone that is driven by the waves
V_{winds}	Speed of longshore flow driven directly by the winds
$\bar{V}$	Mean speed of the flow
w	Surf zone width
x_i	Projection of the i^{th} recovery on the x-axis
x_o	Location of the appropriate release site on the x-axis
$\bar{X}_{t\leq 15}$	Mean SBD displacement function
θ	Angle between wind vector and shore normal with positive angles giving a positive longshore component parallel to the x-axis
σ_x	RMS measure of the random component of SBD displacement
$\sigma_{x(t)}$	RMS measure of the deterministic component of SBD displacement

ϕ_1 Coefficient of proportionality that is function of wind angle as given in Figure 12

ϕ_2 Coefficient of proportionality that is function of wind angle as given in Figure 12

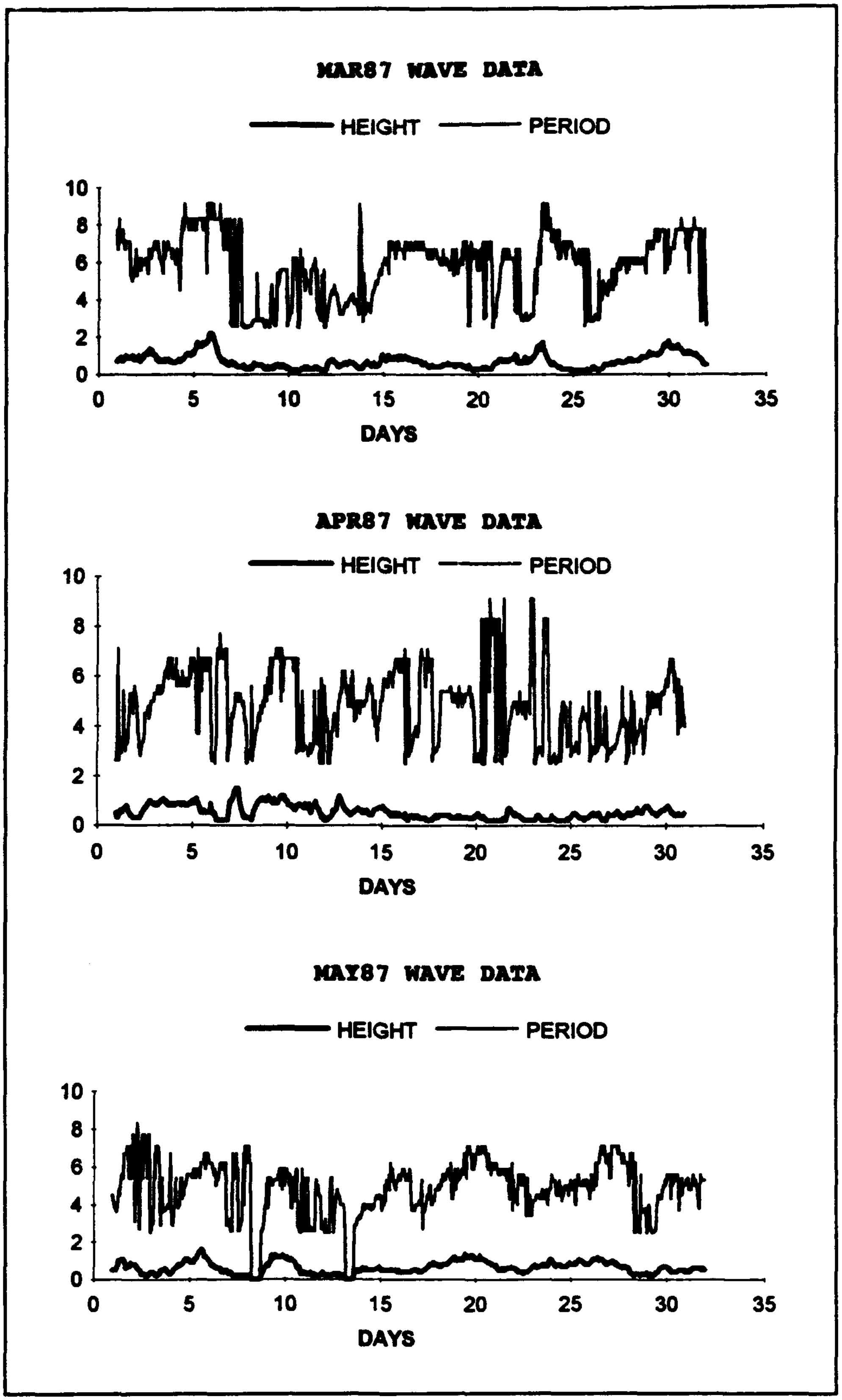
ϕ_2' Proportionality coefficient that is function of wind angle as given in Equation 3

α_b Wave breaker angle

σ Correlation coefficient

Appendix C
Time Series of Hindcast Waves

The wave heights, periods, and directions shown in this appendix are the result of hindcasts using fairly rough parametric wind fields. Hence, although the wave model used has been shown to be quite accurate when driven by accurate winds, the hindcast waves are somewhat rough. In order to improve the accuracy when possible, all measured wave heights and periods were blended into the hindcast data for periods in which they were available. All wave directions are taken from the hindcast results. In these figures, wave heights are in meters, wave periods are in seconds, and wave directions are in degrees relative to shore normal. Positive angles indicate waves approaching from east of shore normal.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DAYS
APR87 WAVE DATA
HEIGHT
PERIOD
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2
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5
10
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DAYS
MAY87 WAVE DATA
HEIGHT
PERIOD
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25
30
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DAYS

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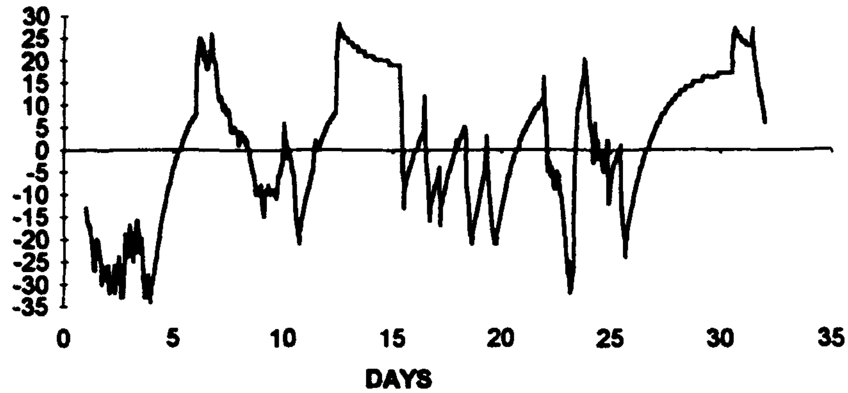

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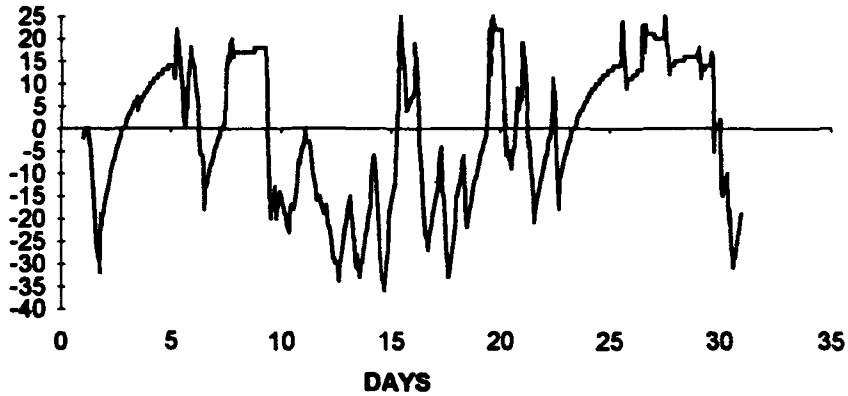

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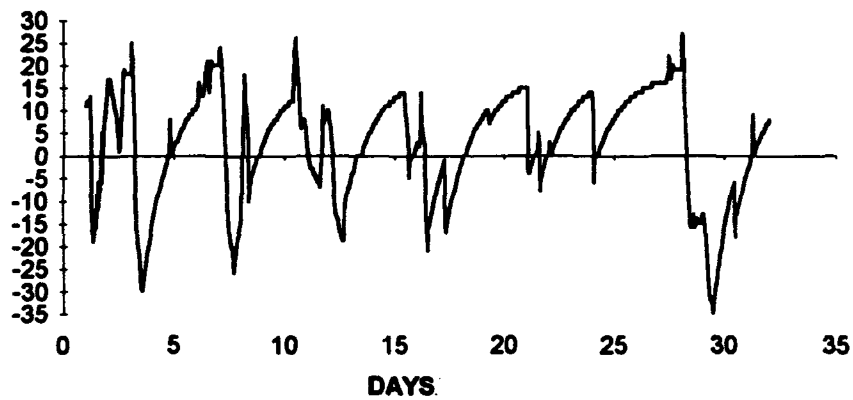

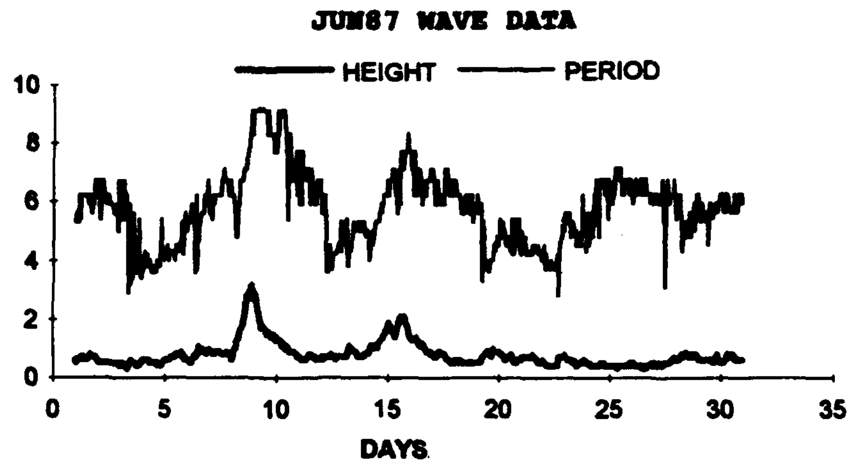
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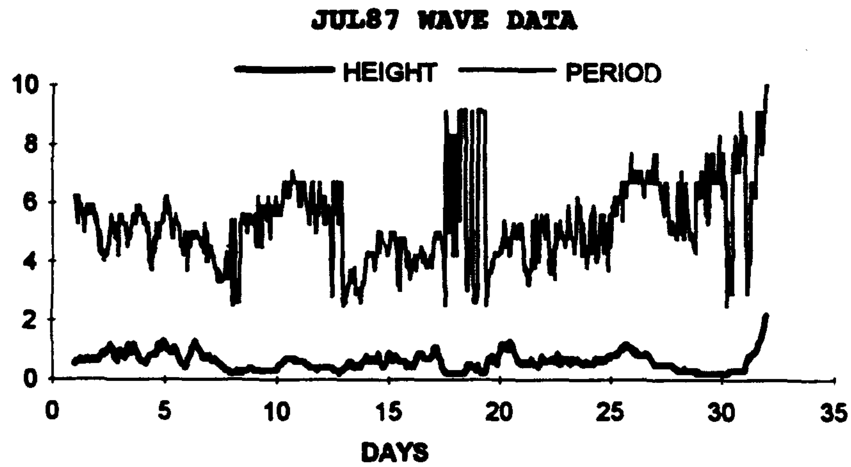
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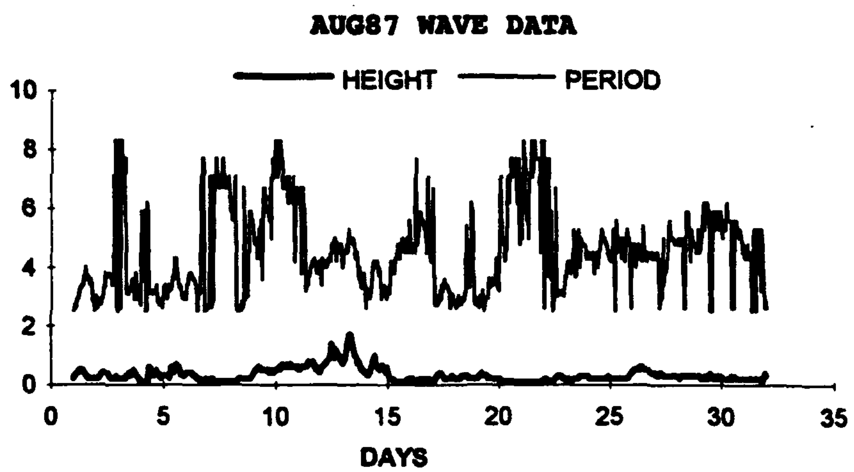
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DAYS

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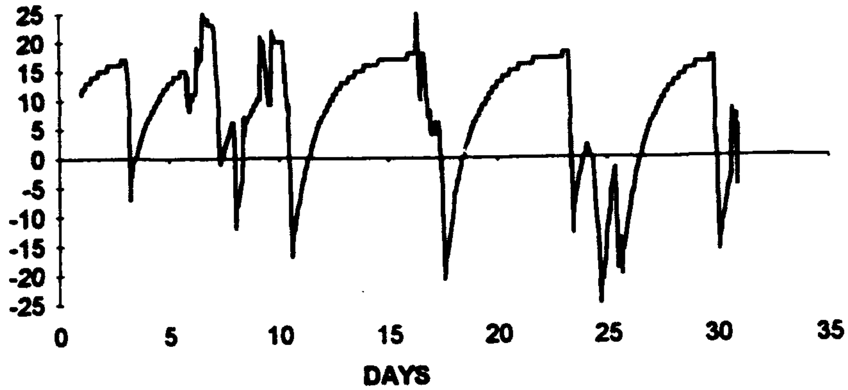

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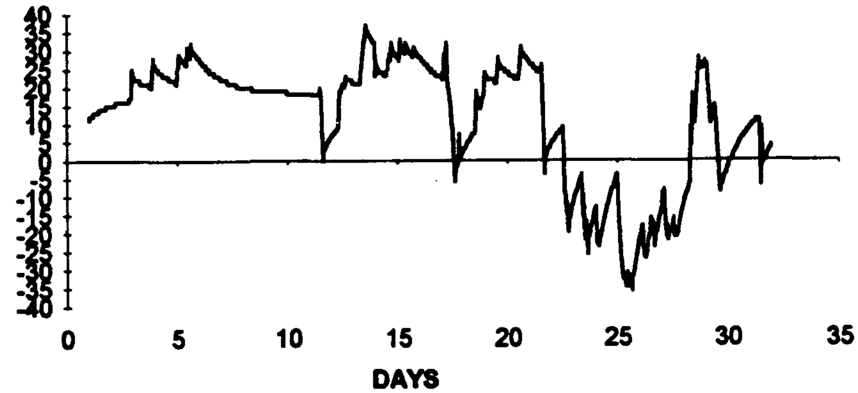

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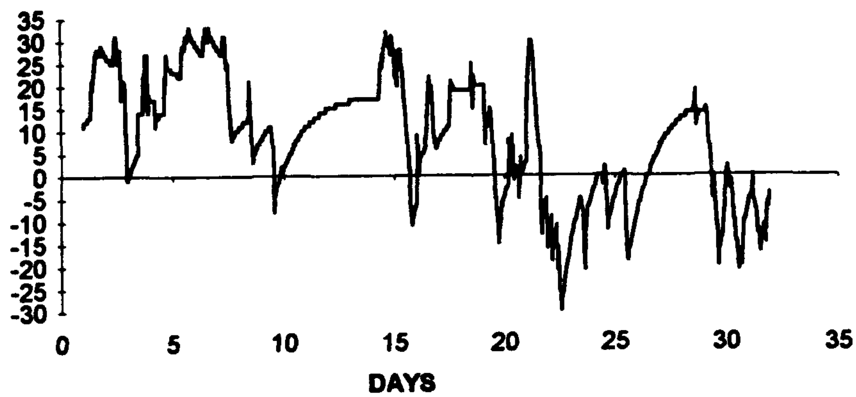

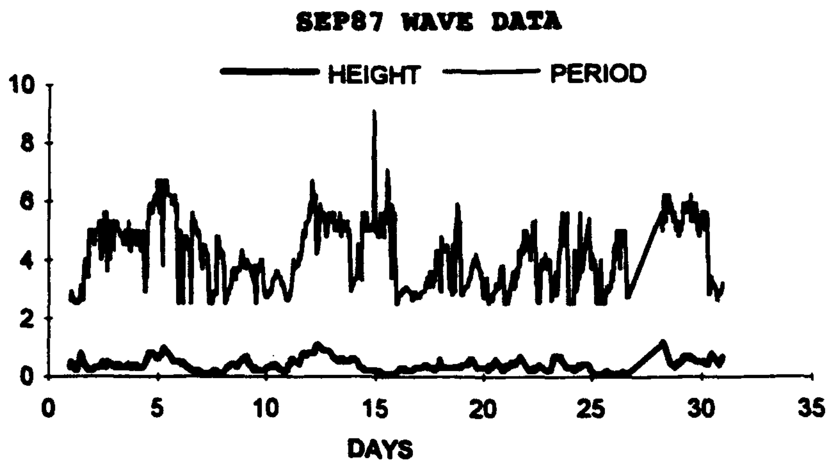
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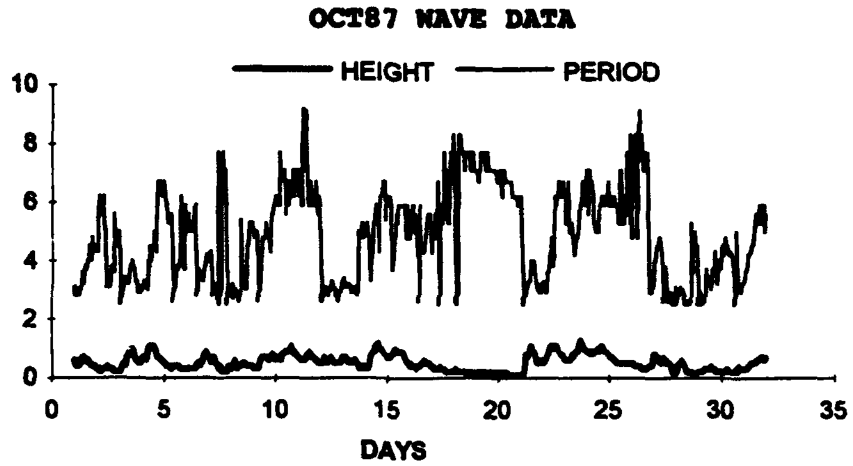
DAYS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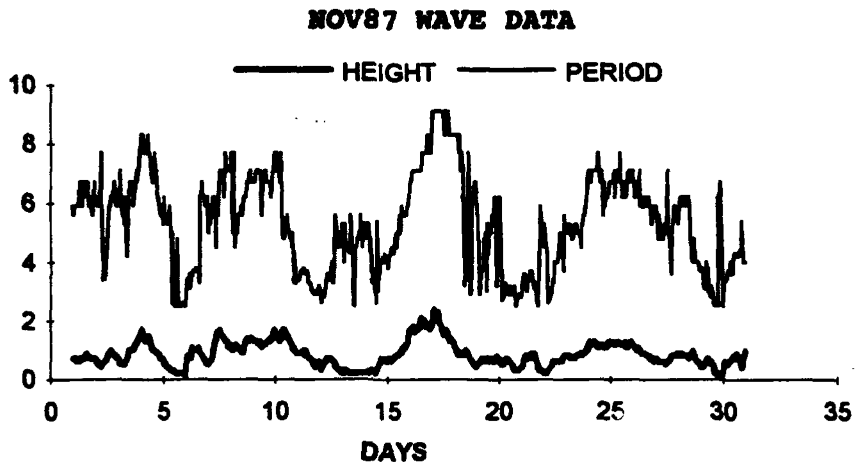
DAYS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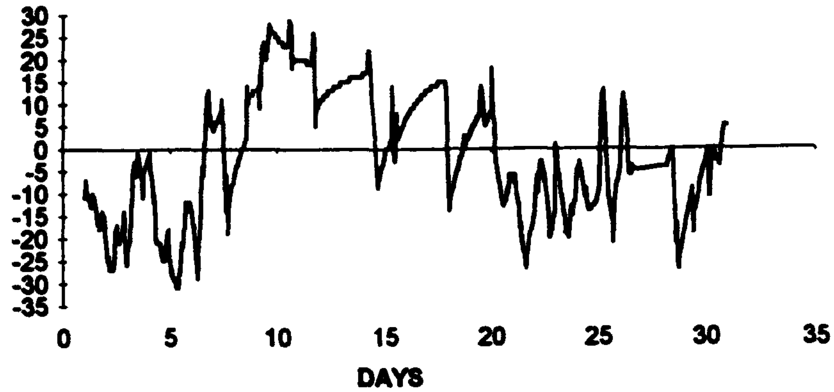
DAYS

SEP87 WAVE DIRECTION



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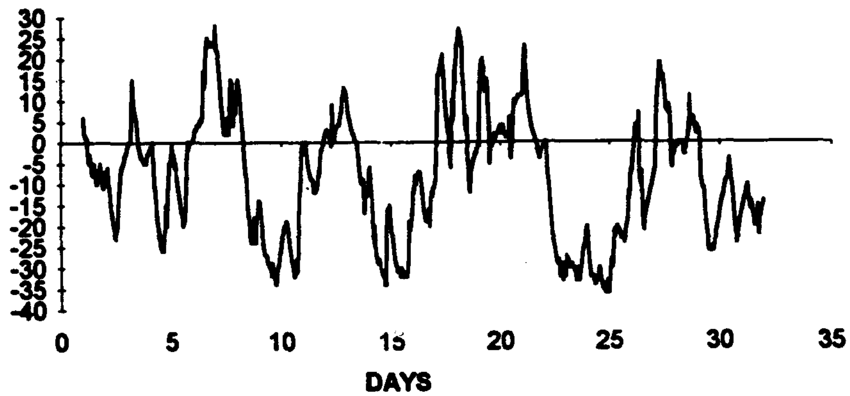

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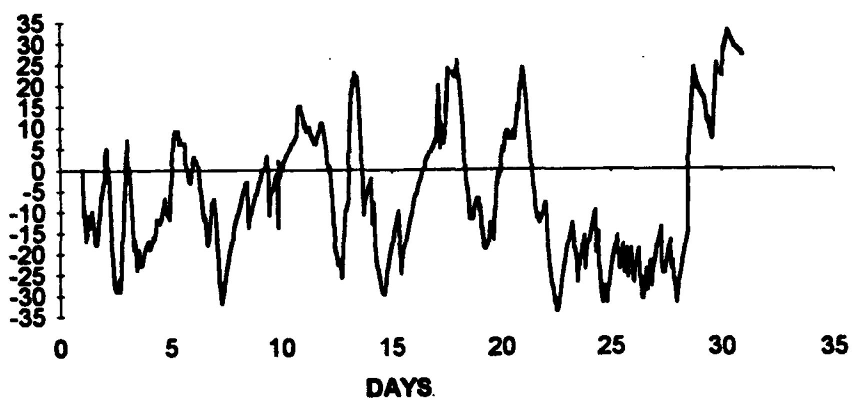

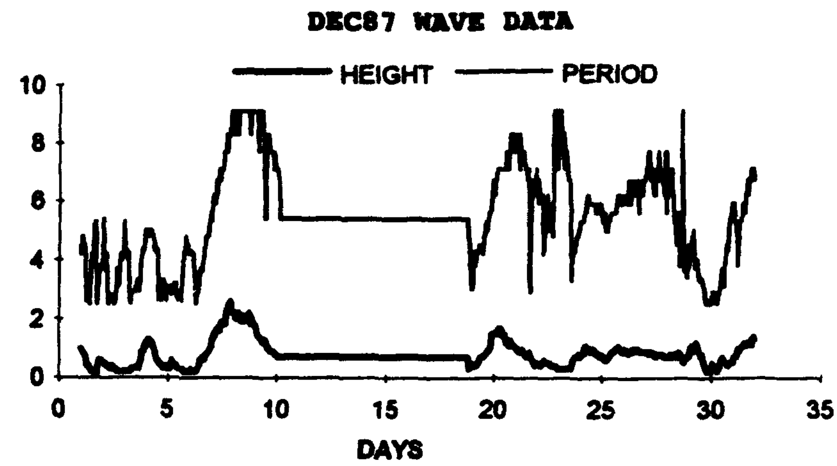
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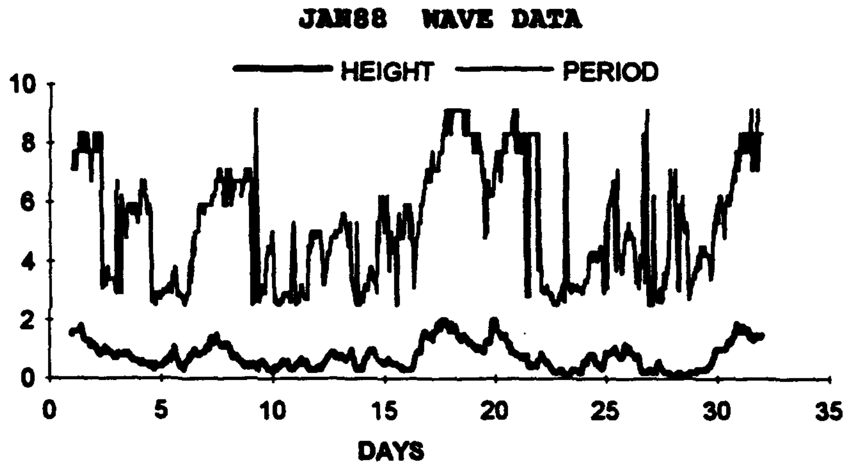
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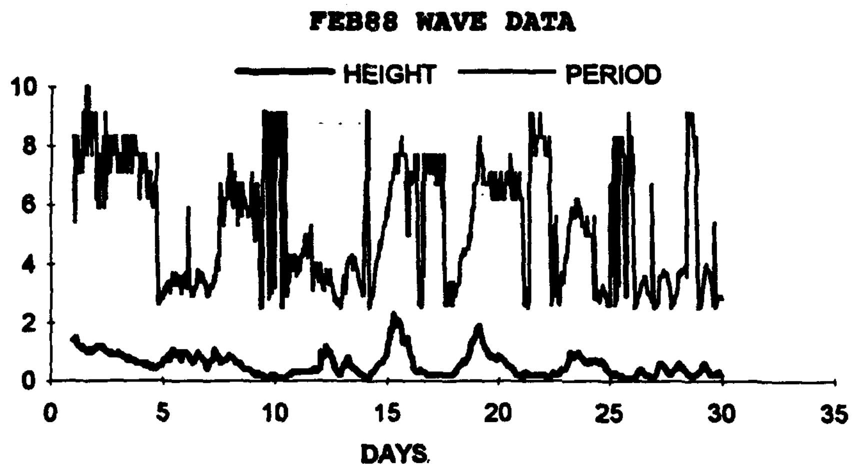
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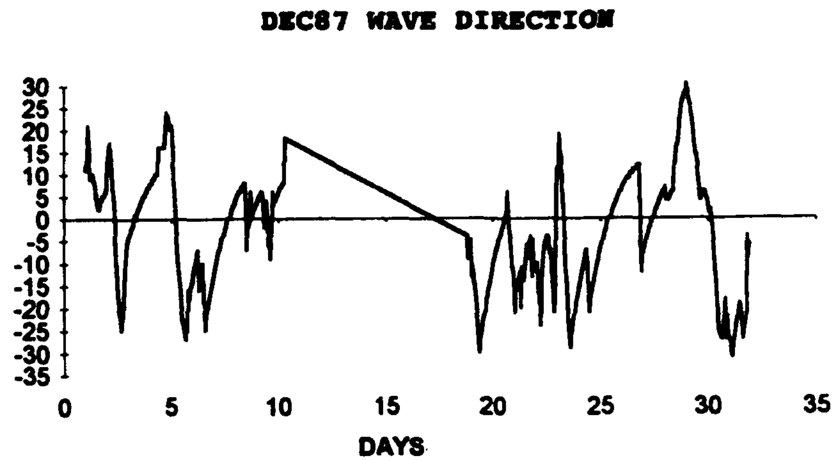
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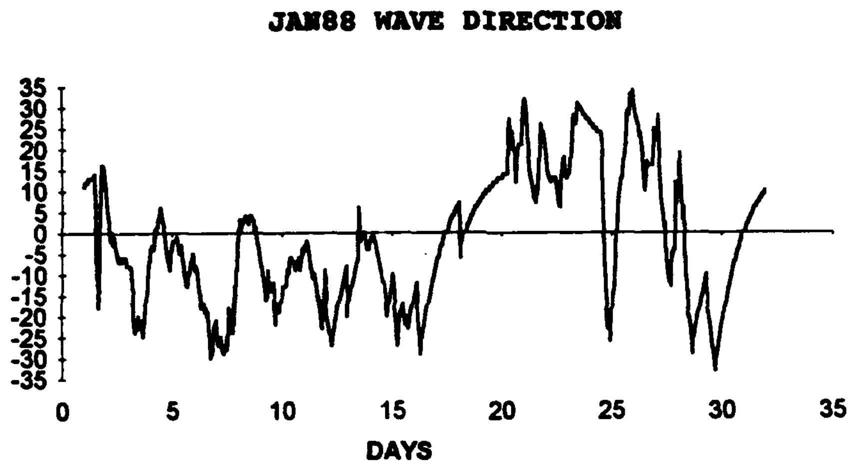
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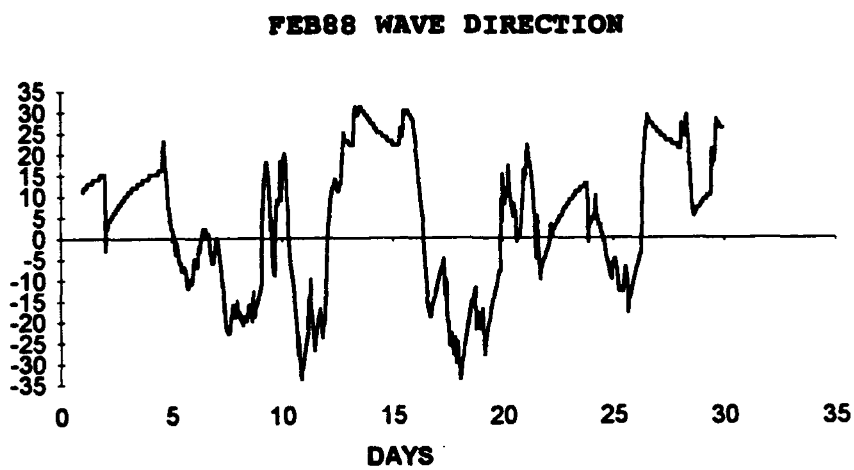
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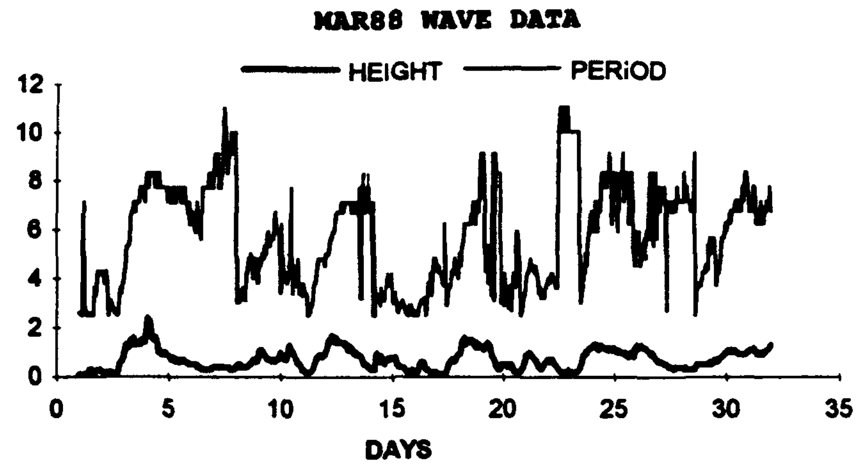
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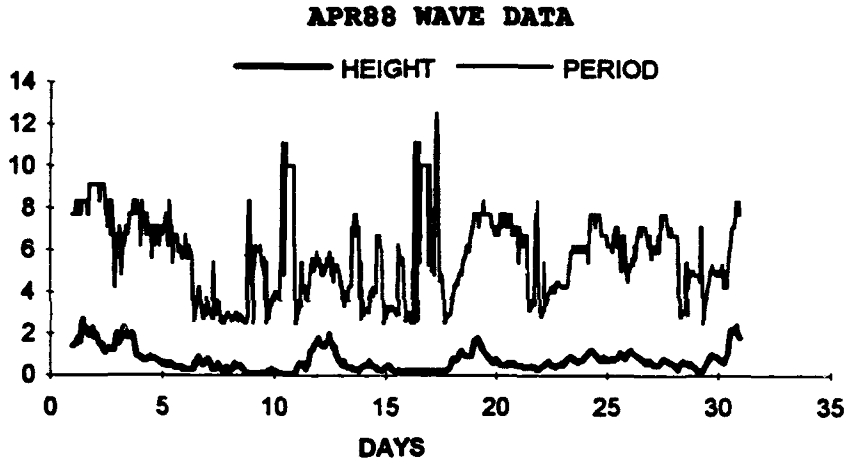
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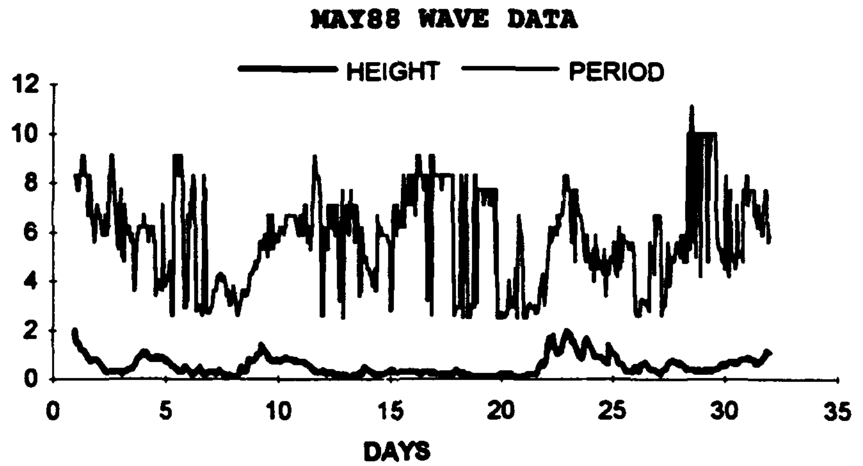
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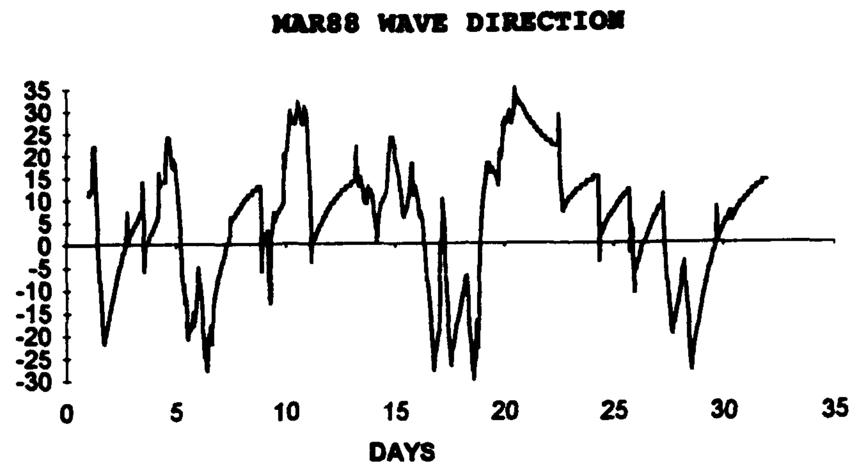
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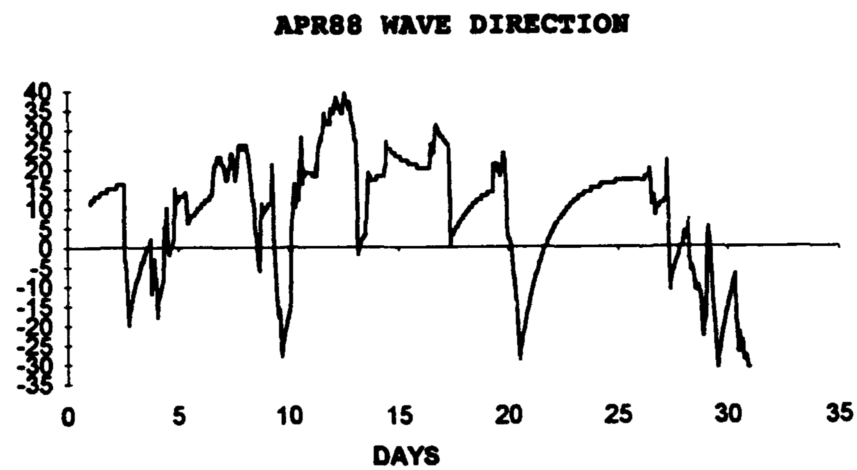
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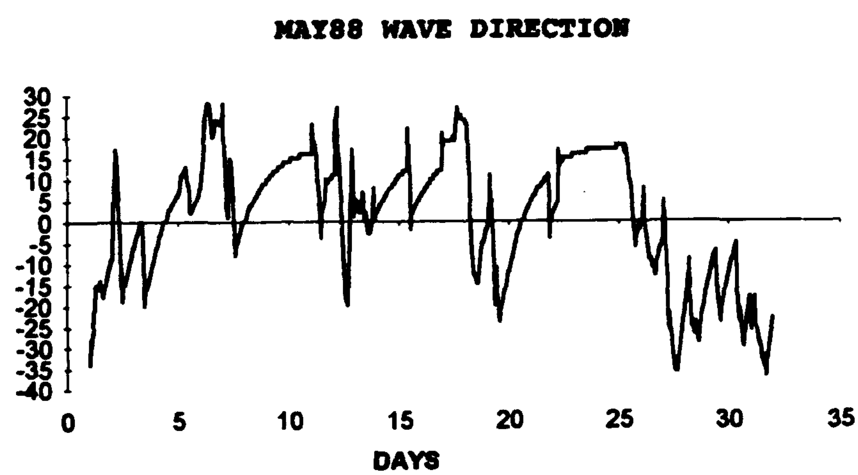
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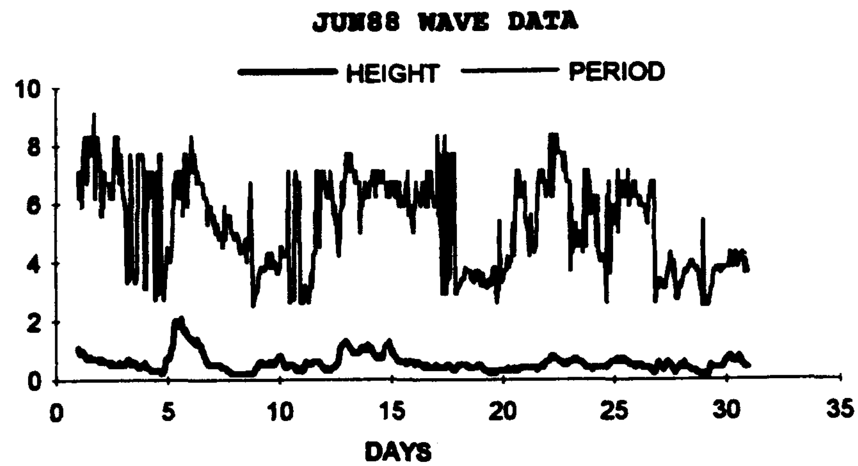

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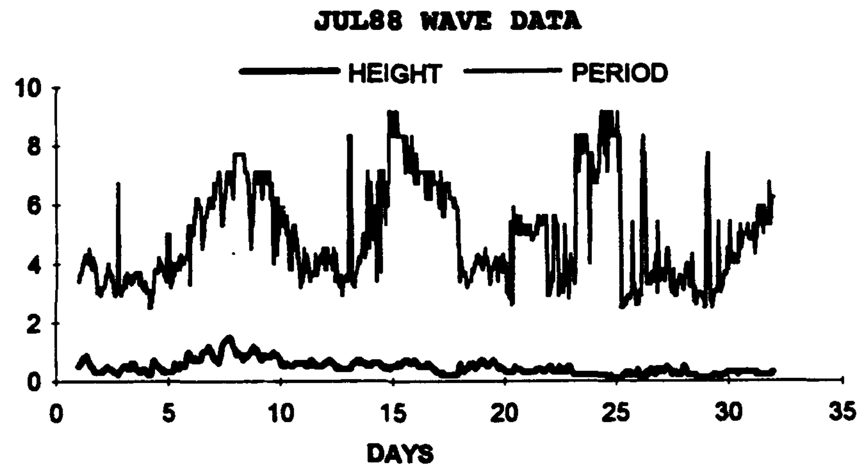

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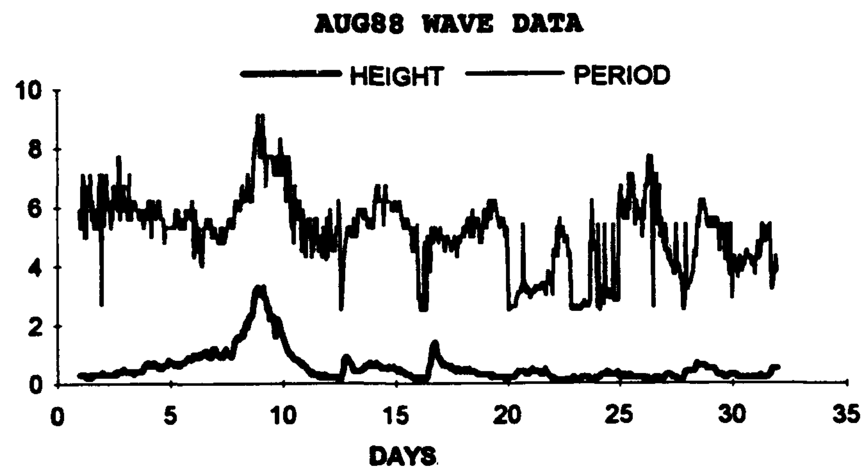

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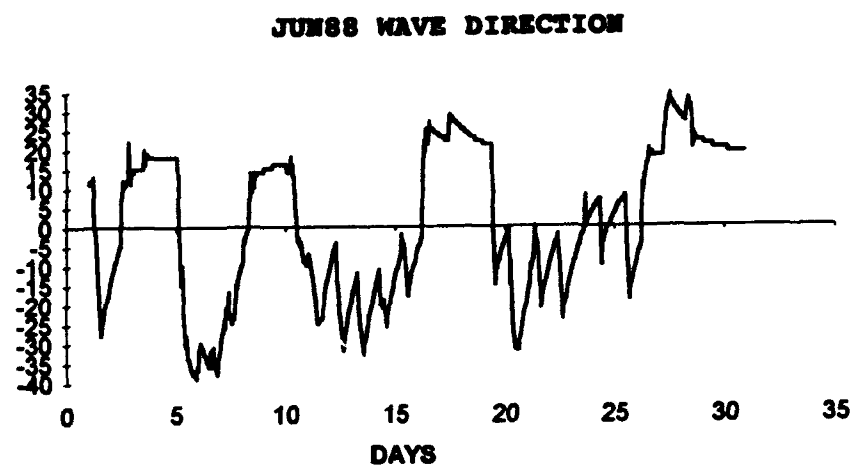
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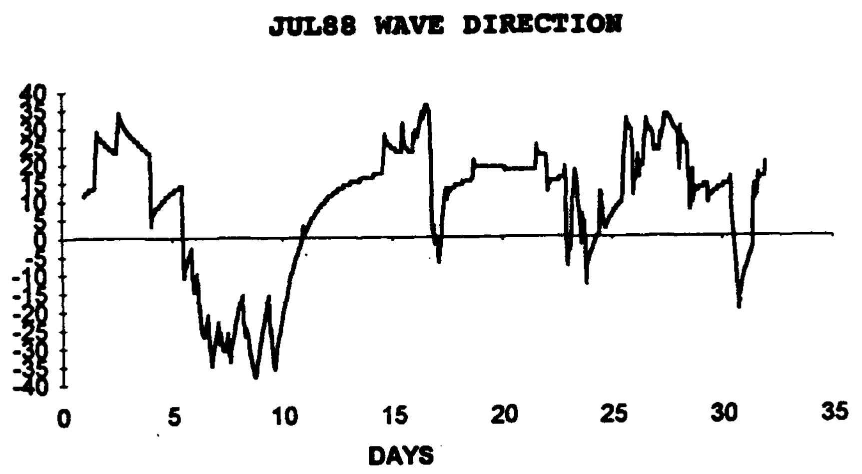
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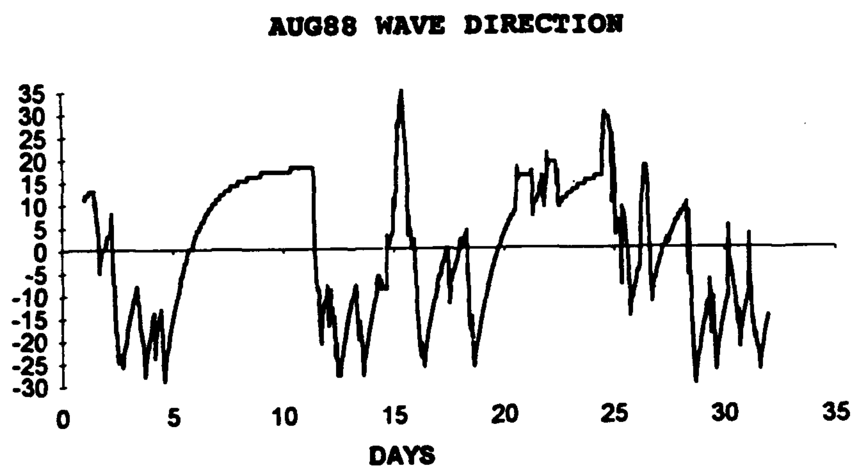
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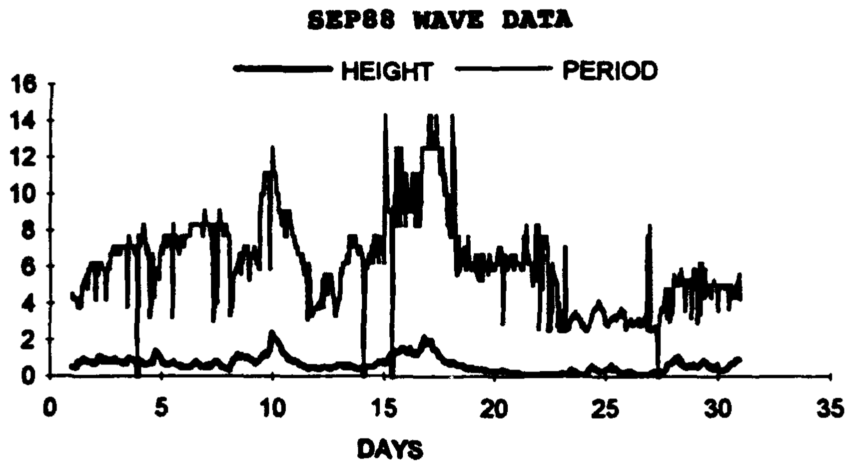
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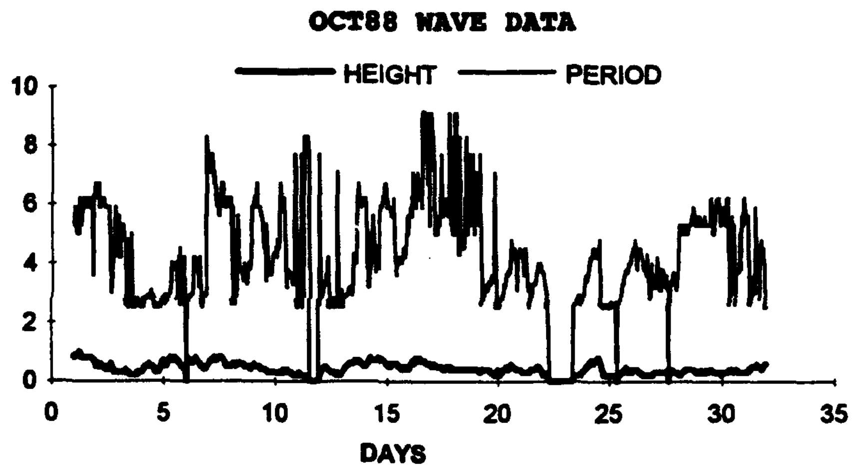
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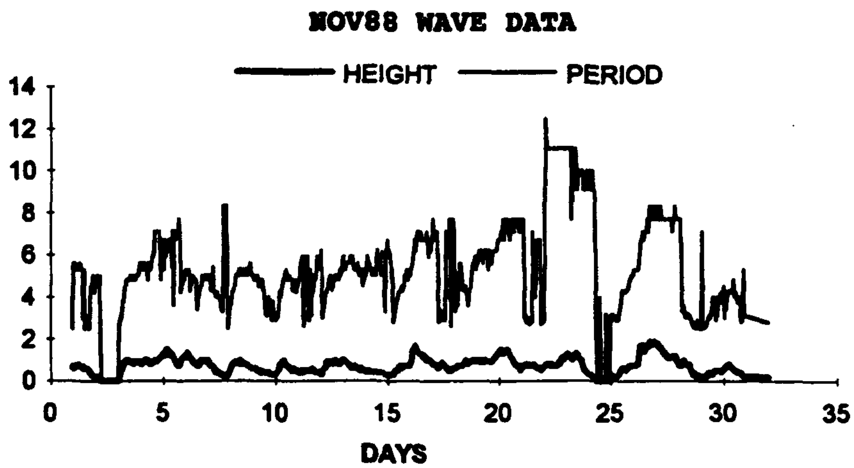
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PERIOD
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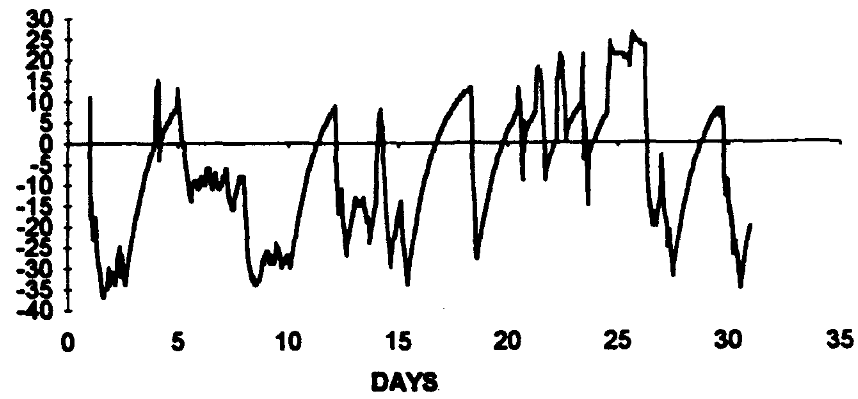
DAYS

SEP88 WAVE DIRECTION



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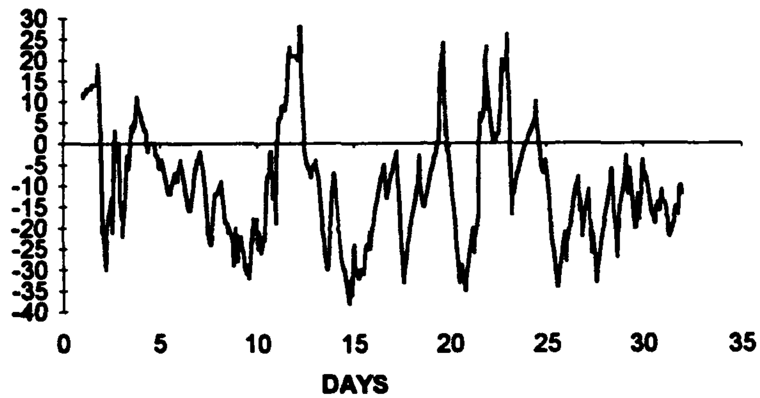

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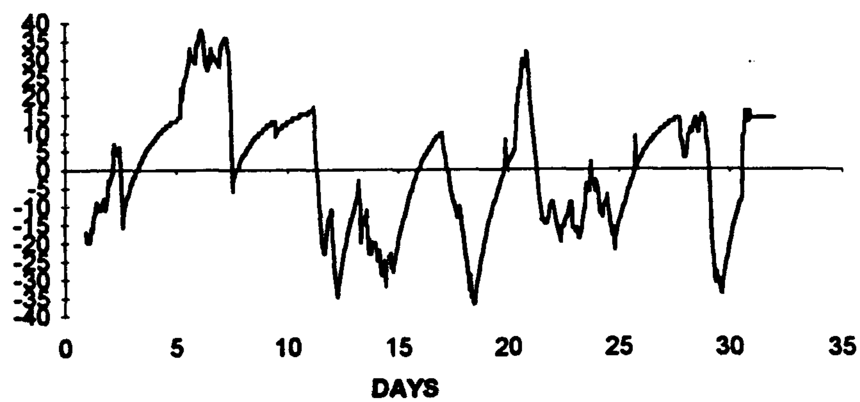

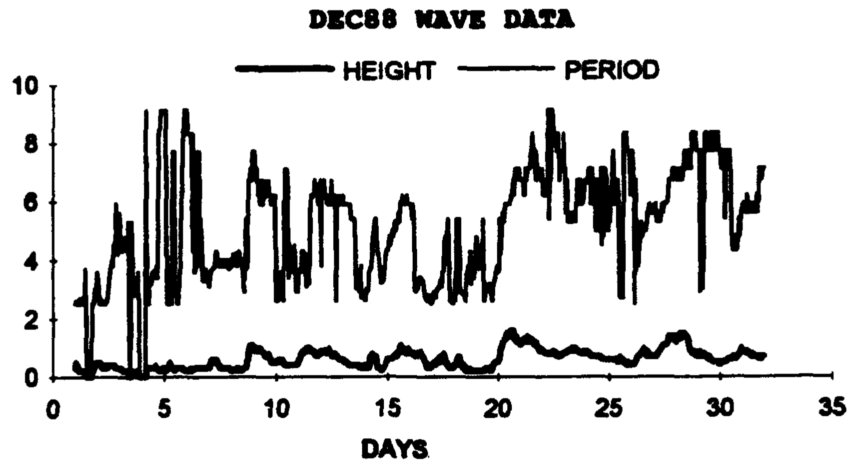
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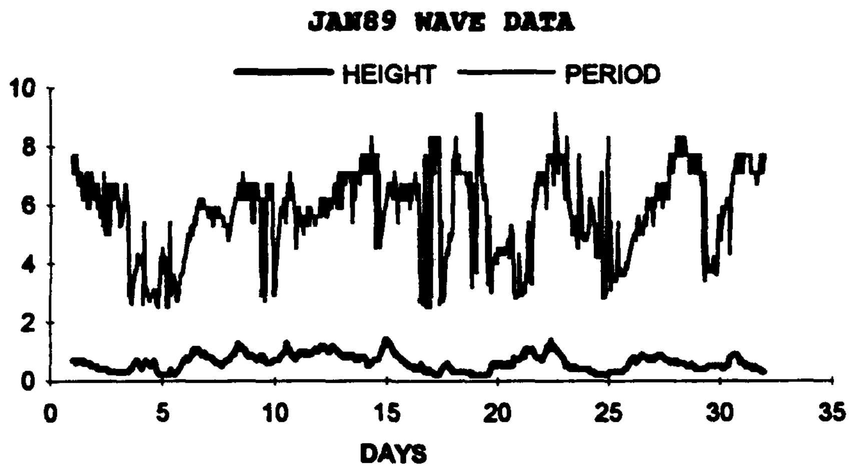
DAYS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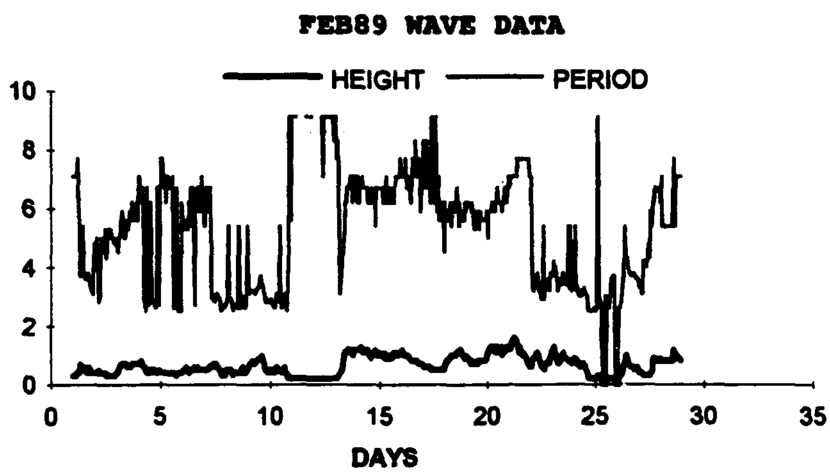
DAYS


FEB89 WAVE DATA
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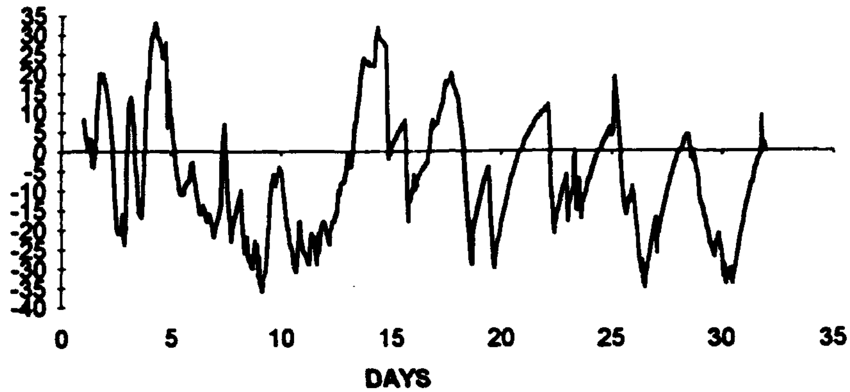
DAYS

DEC88 WAVE DIRECTION



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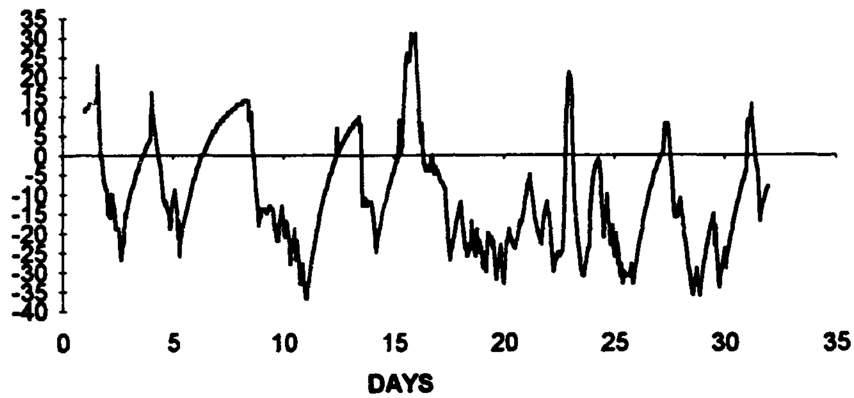
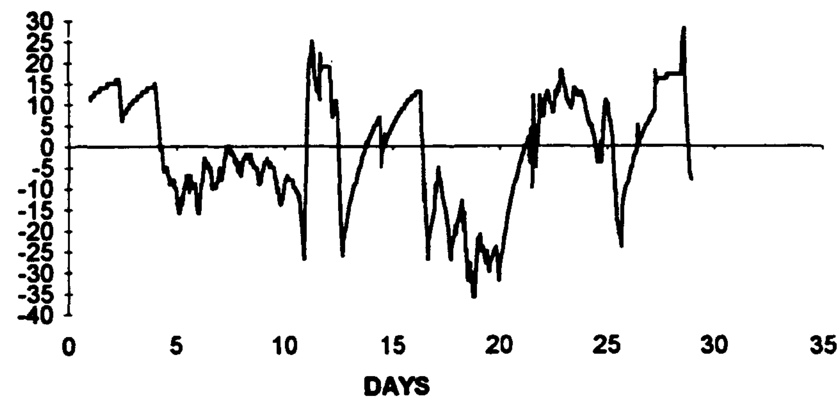
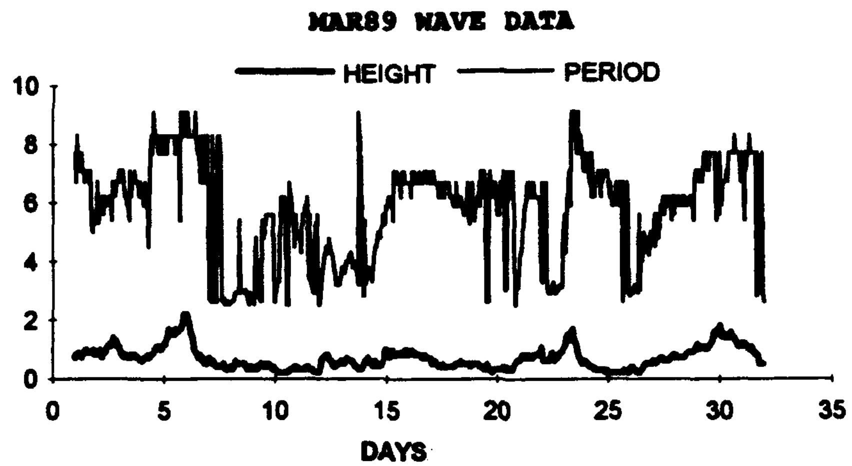


FEB89 WAVE DIRECTION

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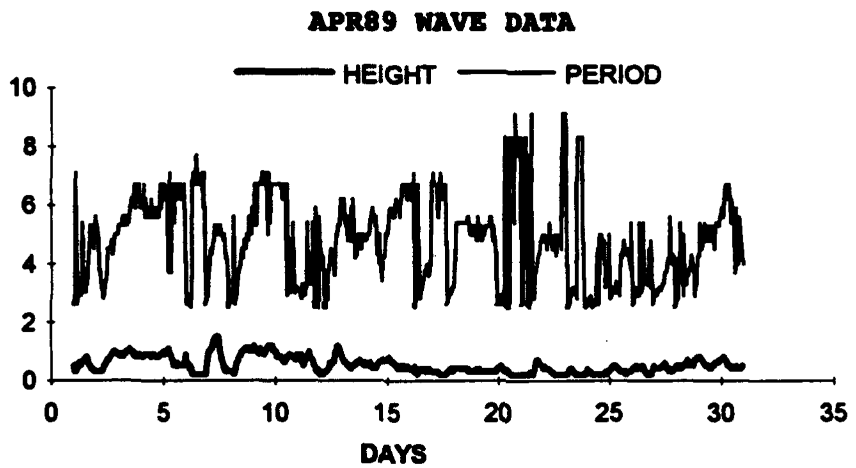
HEIGHT
PERIOD
10
8
6
4
2
0
0
5
10
15
20
25
30
35
DAYS


APR89 WAVE DATA
HEIGHT
PERIOD
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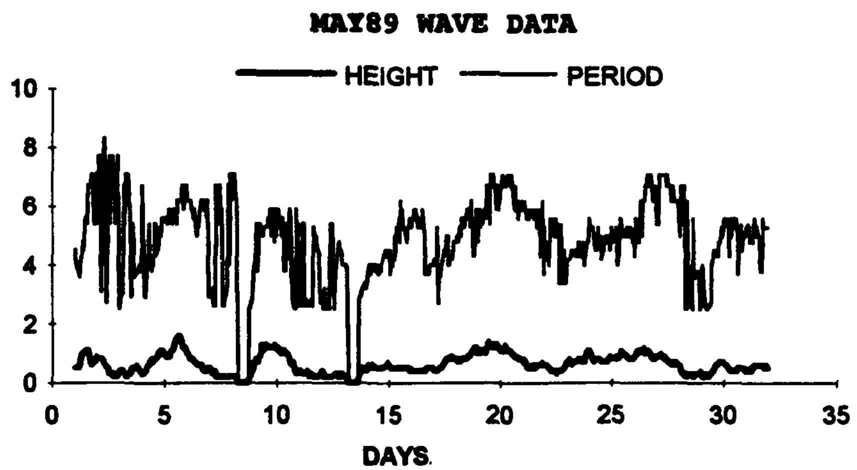
8
6
4
2
0
0
5
10
15
20
25
30
35
DAYS


MAY89 WAVE DATA
HEIGHT
PERIOD
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8
6
4
2
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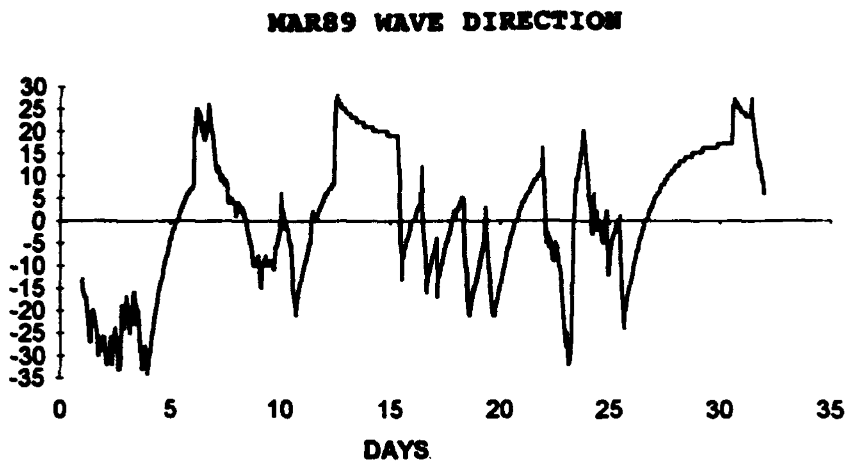
0
5
10
15
20
25
30
35
DAYS.


MAR89 WAVE DIRECTION
30
25
20
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10
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-15
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30
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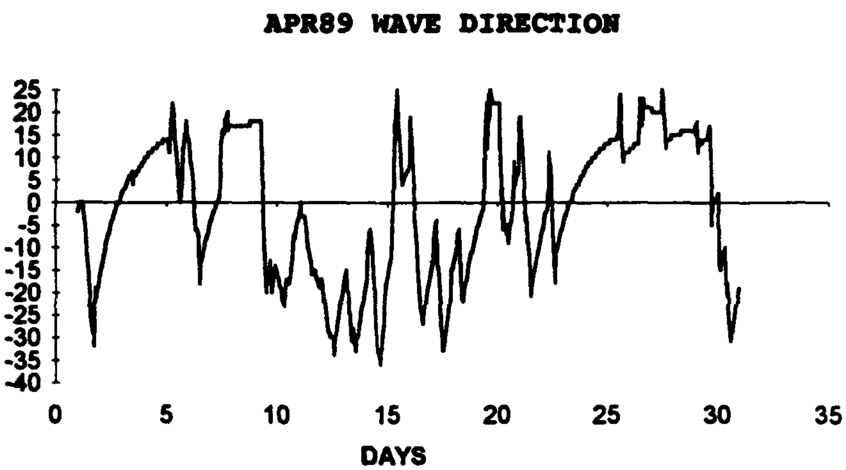
DAYS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20
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10
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-35
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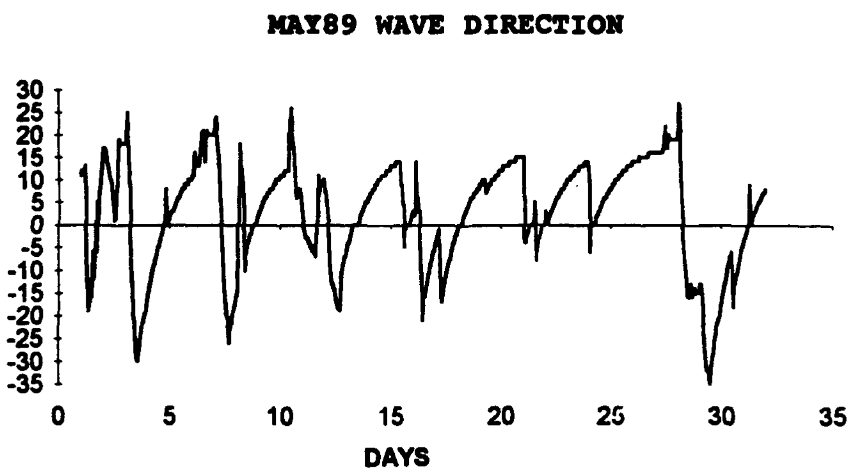
20
25
30
35
DAYS


MAY89 WAVE DIRECTION
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25
20
15
10
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-5
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-15
-20
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-30
-35
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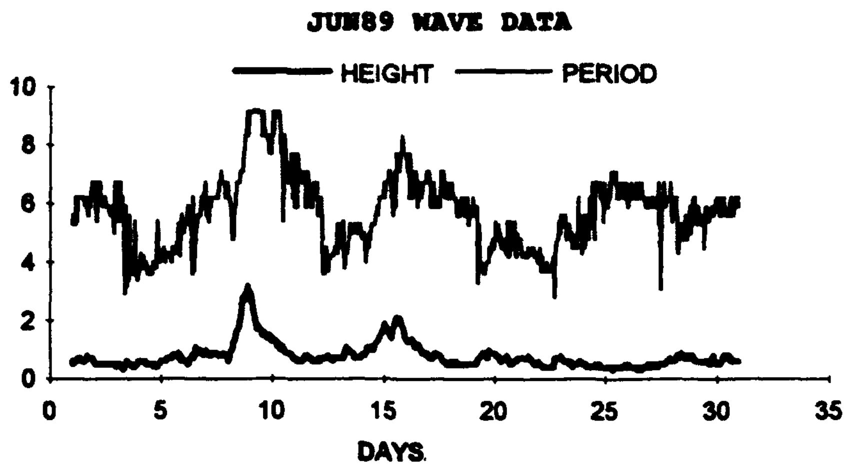
20
25
30
35
DAYS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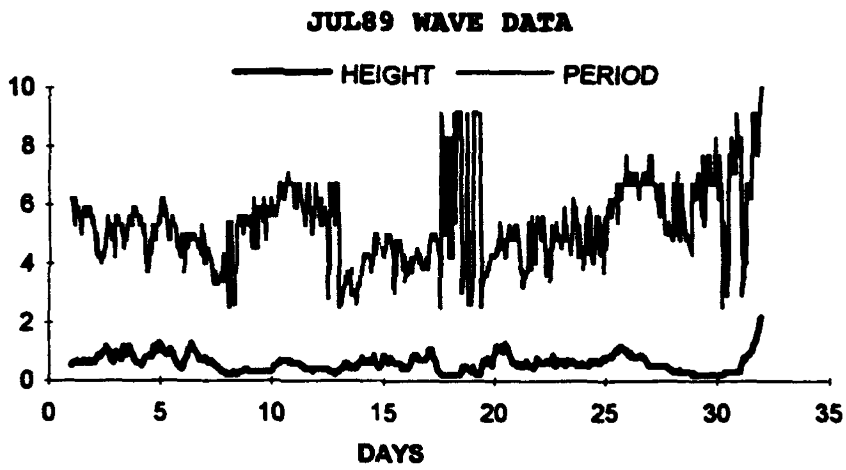
HEIGHT
PERIOD
10
8
6
4
2
0
0
5
10
15
20
25
30
35
DAYS


JUL89 WAVE DATA
HEIGHT
PERIOD
10
8
6
4
2
0
0
5
10
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20
25
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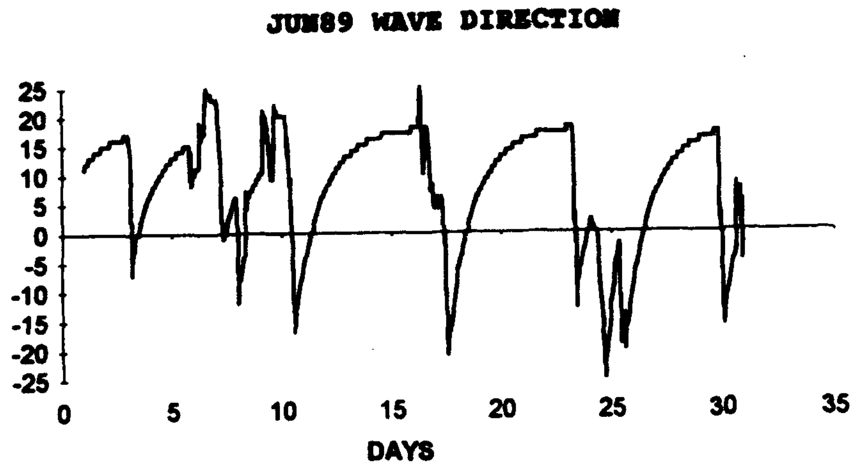
35
DAYS


JUN89 WAVE DIRECTION
25
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10
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-5
-10
-15
-20
-25
0
5
10
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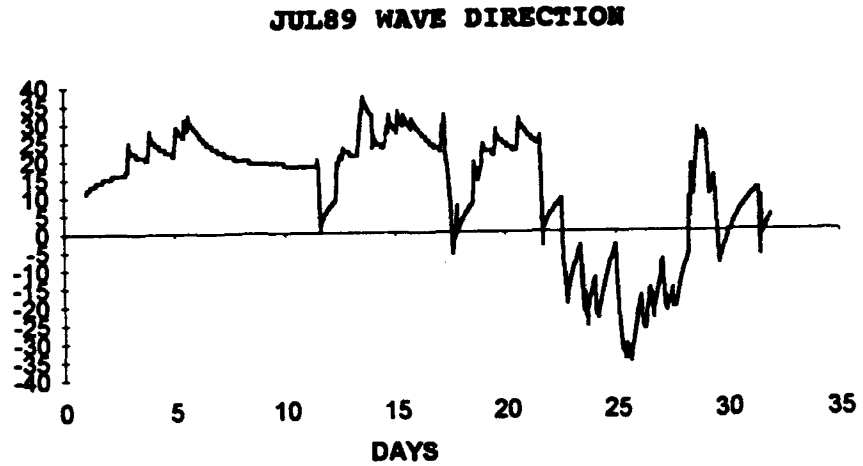
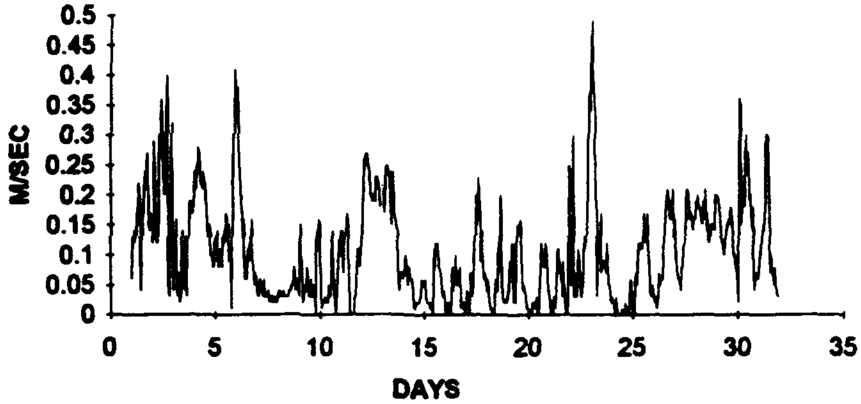
20
25
30
35
DAYS


JUL89 WAVE DIRECTION
0
5
10
15
20
25
30
35
DAYS

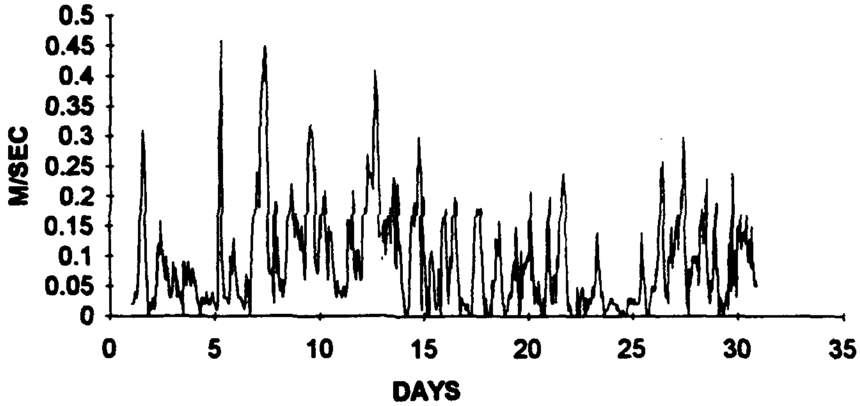
Appendix D
Time Series of Hindcast Wind-Driven Currents

The currents in this appendix are developed from the application of OCTI's parametric current model. Winds to drive the model are taken from local buoy measurements whenever possible. In cases where no local buoy measurements were available, winds were estimated from weather map data at land stations and then were transformed to represent over water wind speeds and directions. The direction of current vectors are in degrees clockwise from the east shore, so that 90° indicates a current heading directly onshore, and 180° indicates currents going alongshore toward the east.

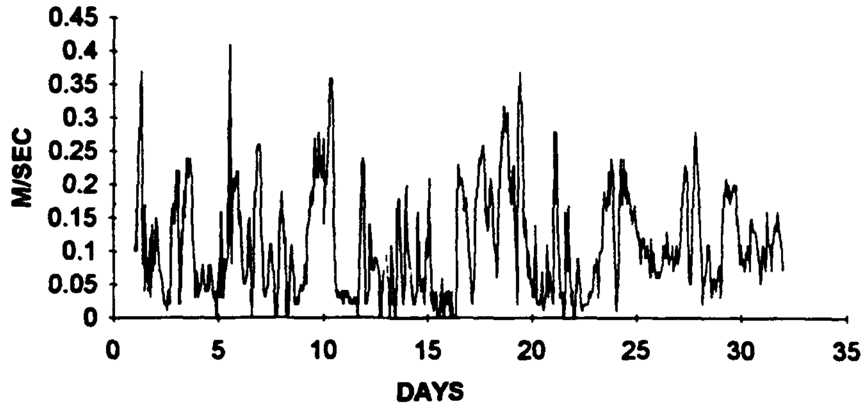
MAR87 CURRENT VELOCITIES



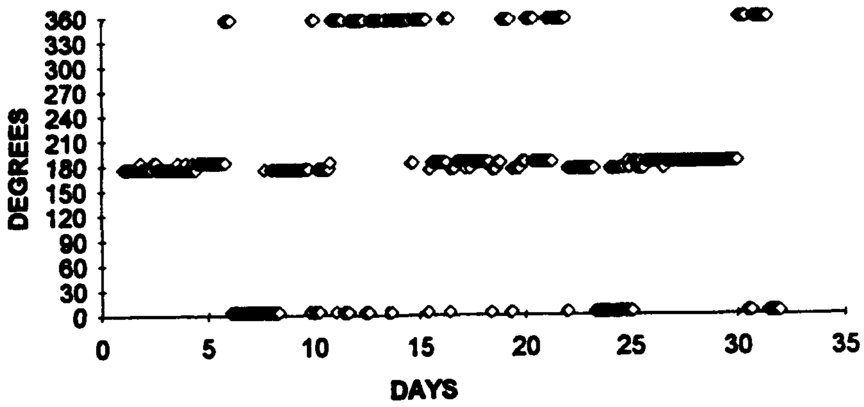
APR87 CURRENT VELOCITIES



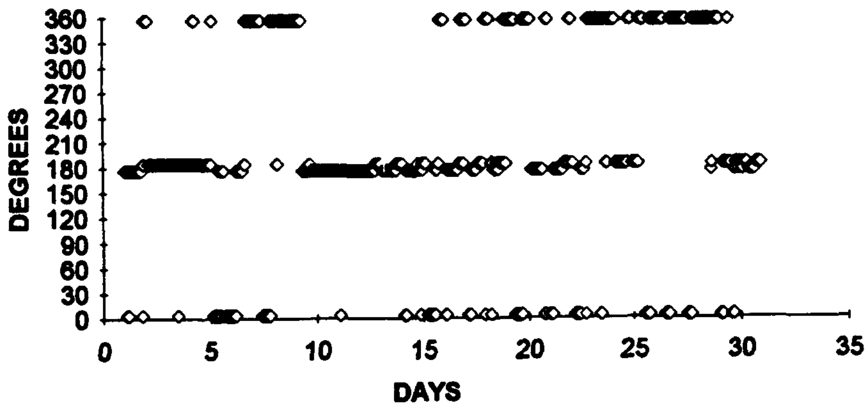
MAY87 CURRENT VELOCITIES



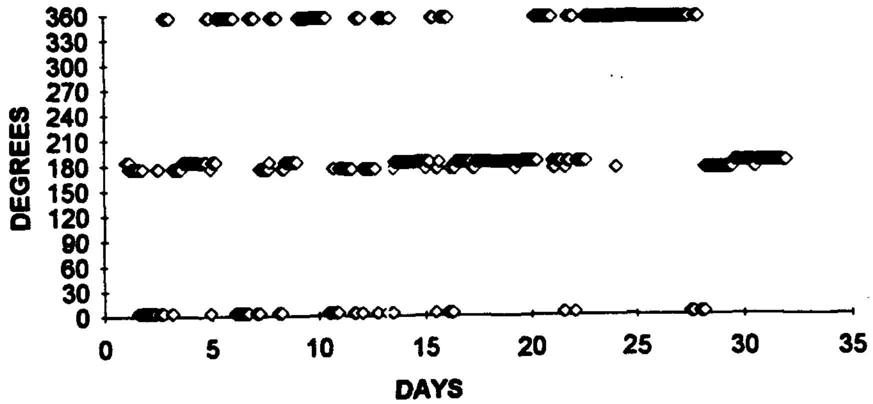
MAR87 CURRENT DIRECTIONS



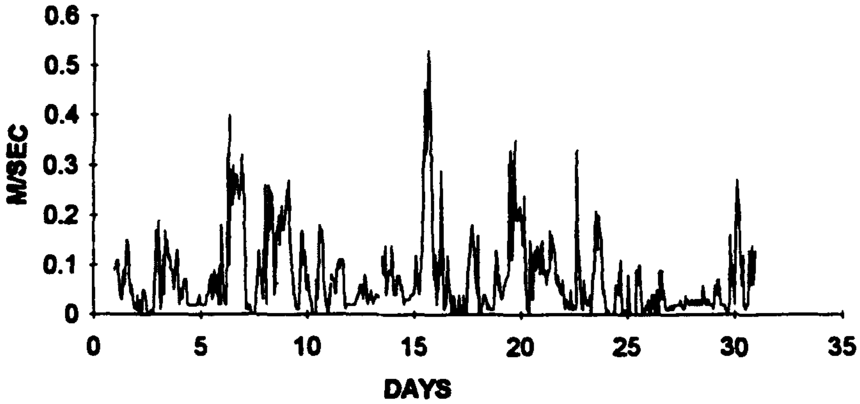
APR87 CURRENT DIRECTIONS



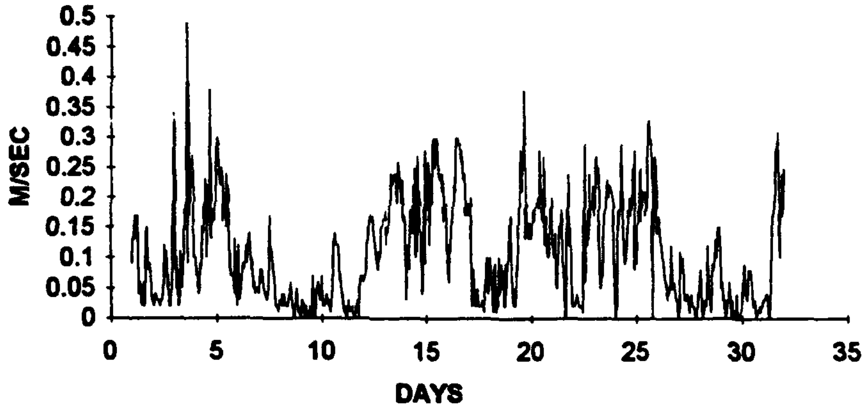
MAY87 CURRENT DIRECTIONS



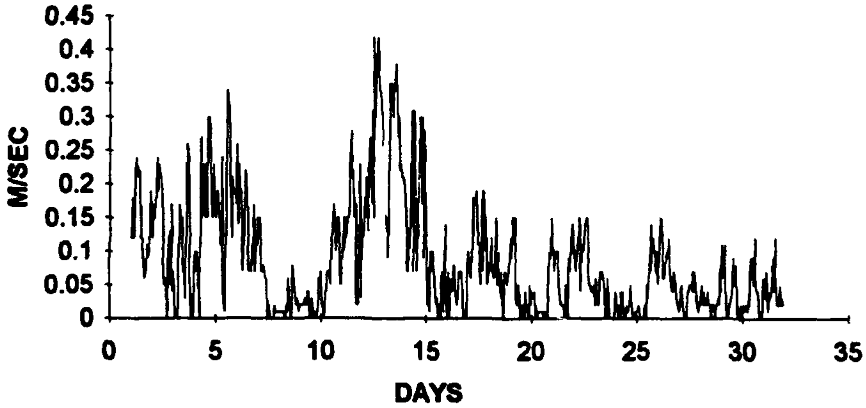
JUN87 CURRENT VELOCITIES

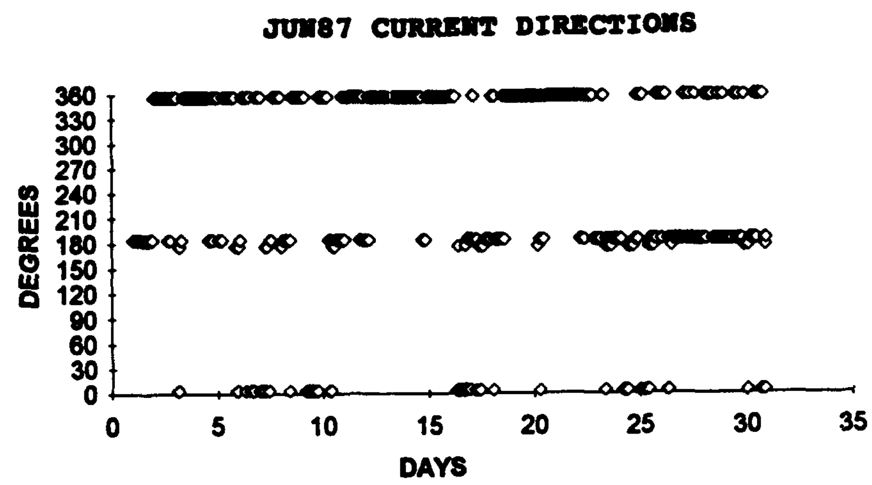


JUL87 CURRENT VELOCITIES



AUG87 CURRENT VELOCITIES

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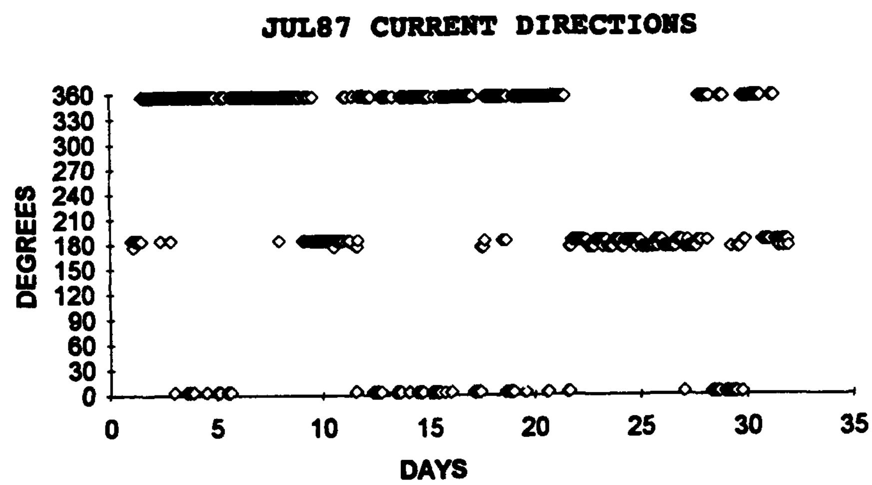
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
5
10
15
20
25
30
35
DAYS


JUL87 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
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10
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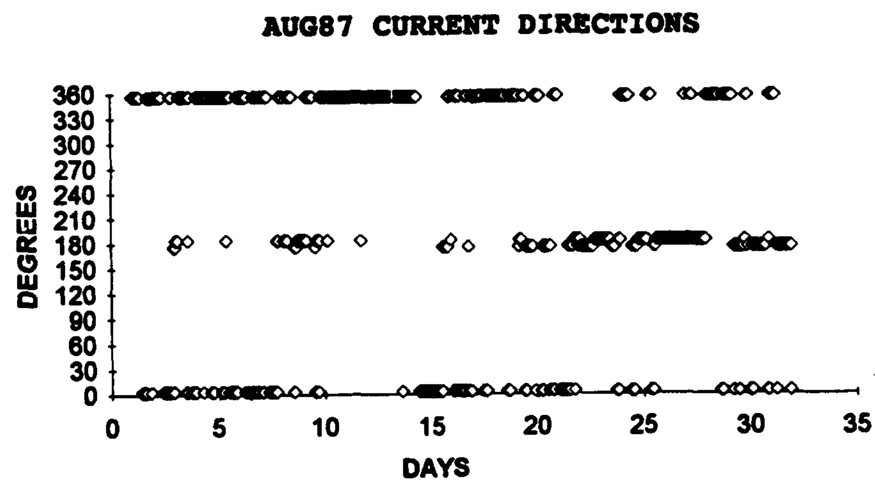
20
25
30
35
DAYS


AUG87 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
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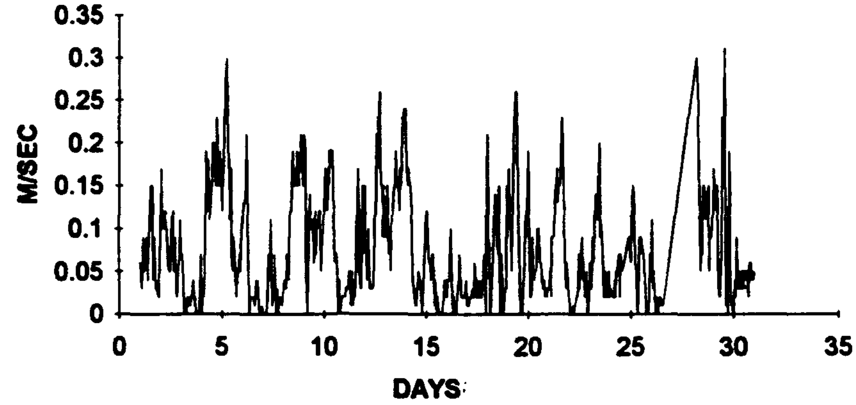
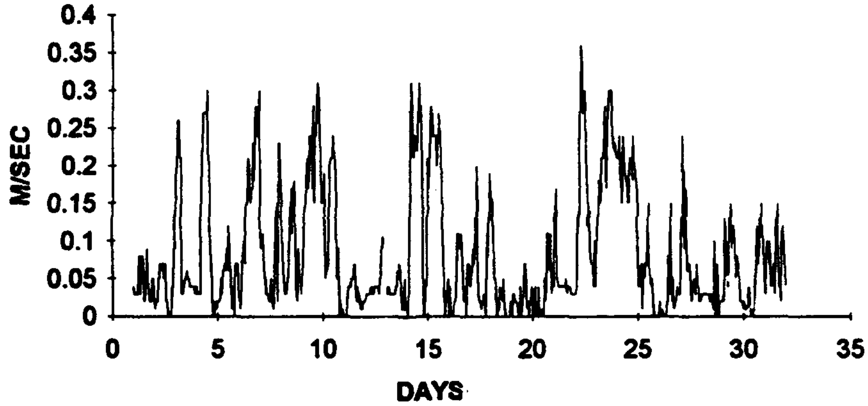
10
15
20
25
30
35
DAYS

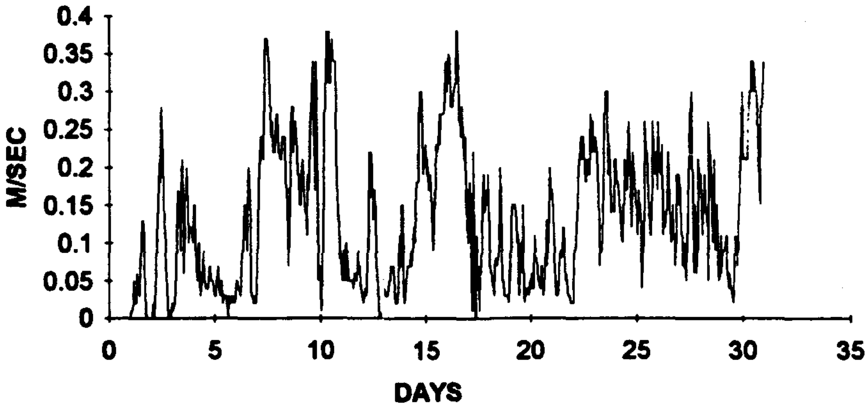
SEP87 CURRENT VELOCITIES



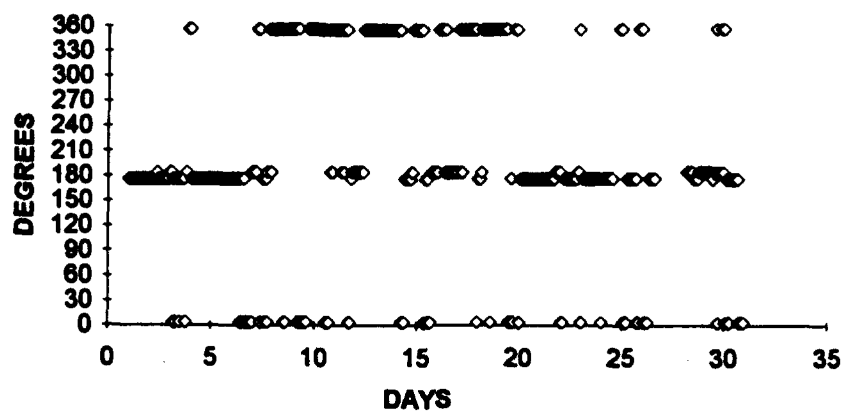
OCT87 CURRENT VELOCITIES



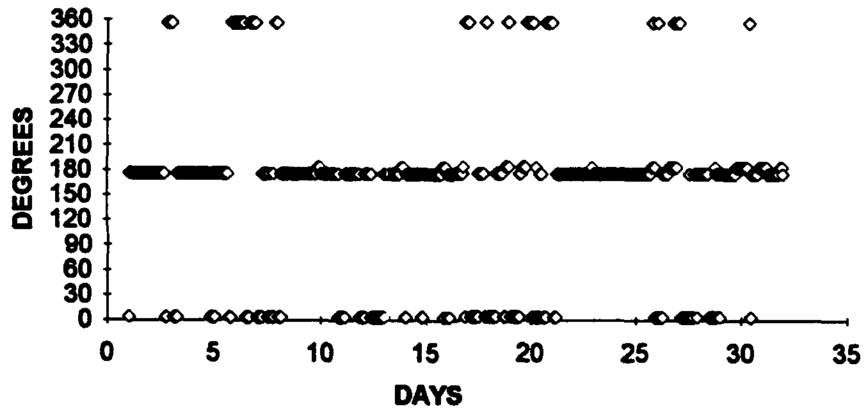
NOV87 CURRENT VELOCITIES



SEP87 CURRENT DIRECTIONS



OCT87 CURRENT DIRECTIONS



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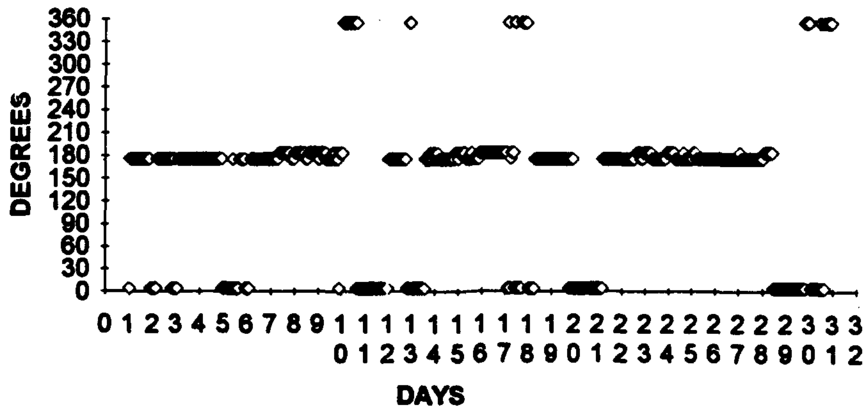

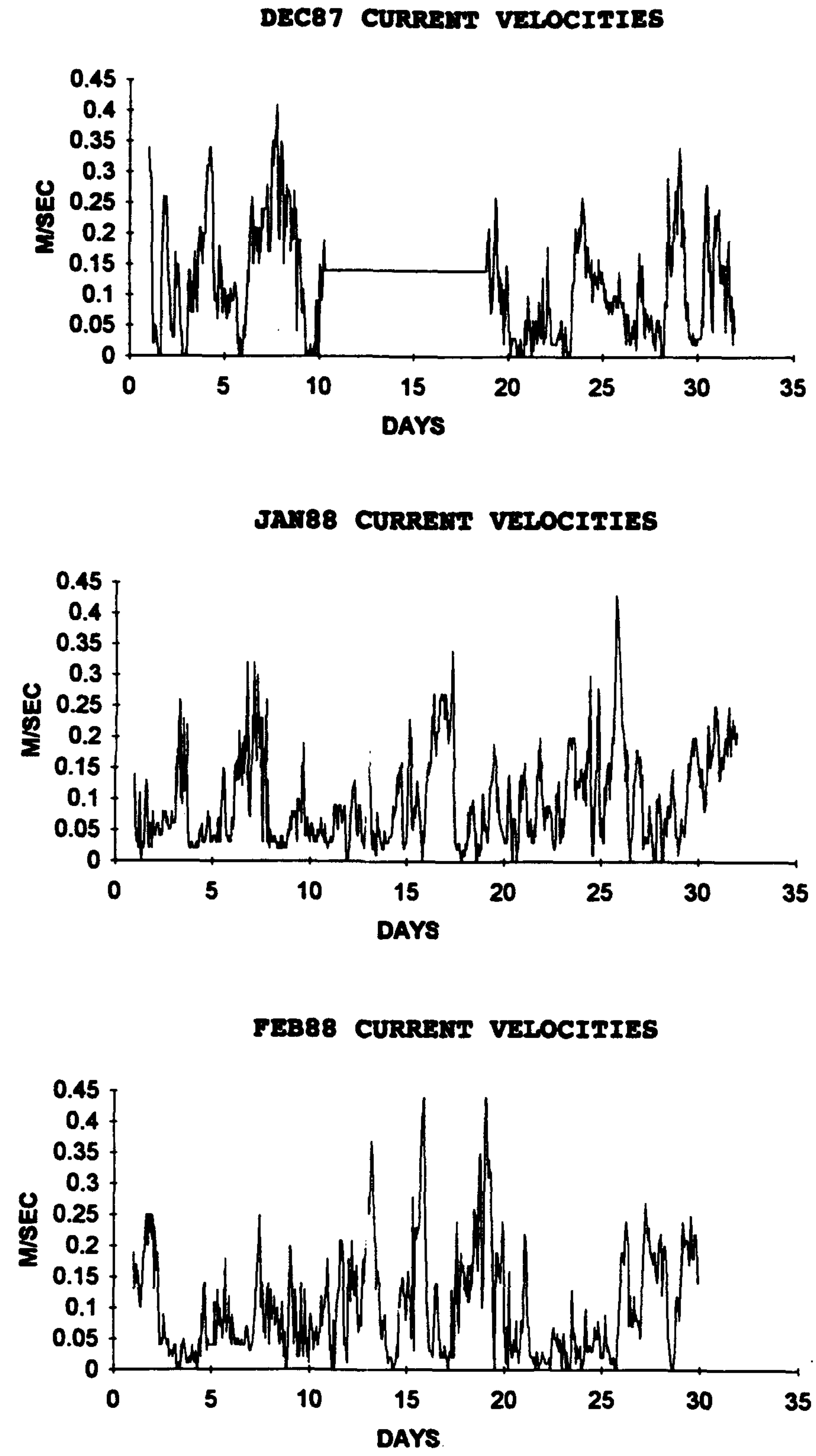
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M/SEC
DAYS
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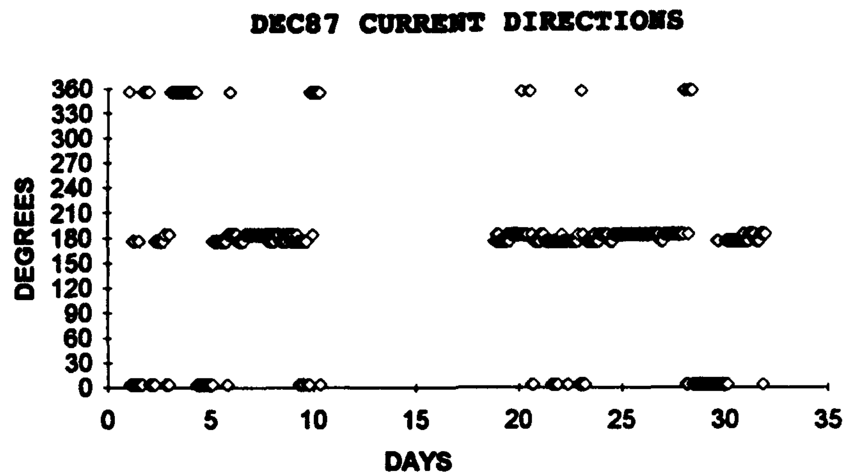
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
JAN88 CURRENT VELOCITIES
M/SEC
DAYS
FEB88 CURRENT VELOCITIES
M/SEC
DAYS


DEC87 CURRENT DIRECTIONS
DEGREES
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330
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180
150
120
90
60
30
0
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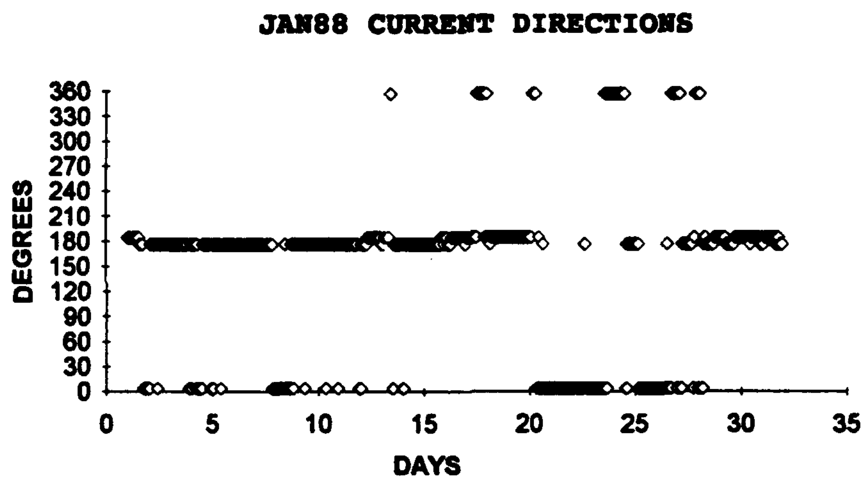
20
25
30
35
DAYS


JAN88 CURRENT DIRECTIONS
DEGREES
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120
90
60
30
0
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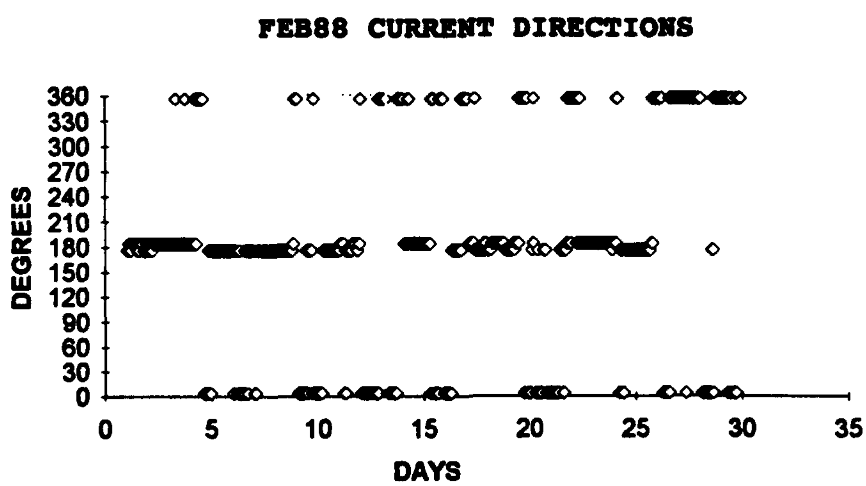
20
25
30
35
DAYS


FEB88 CURRENT DIRECTIONS
DEGREES
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330
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150
120
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60
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10
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20
25
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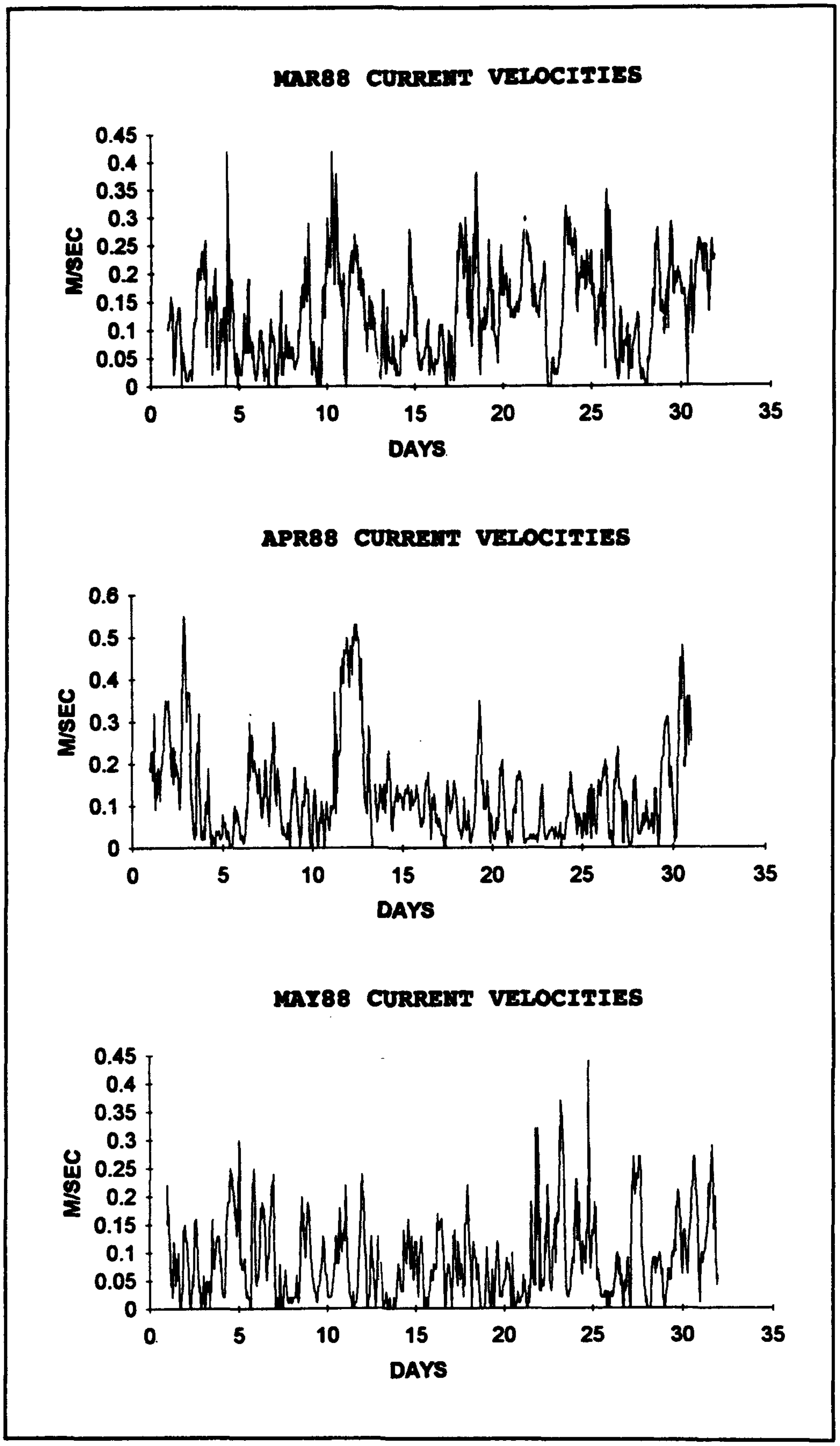
35
DAYS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0.25
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0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
DAYS
APR88 CURRENT VELOCITIES
M/SEC
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35
DAYS
MAY88 CURRENT VELOCITIES
M/SEC
0.45
0.4
0.35
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10
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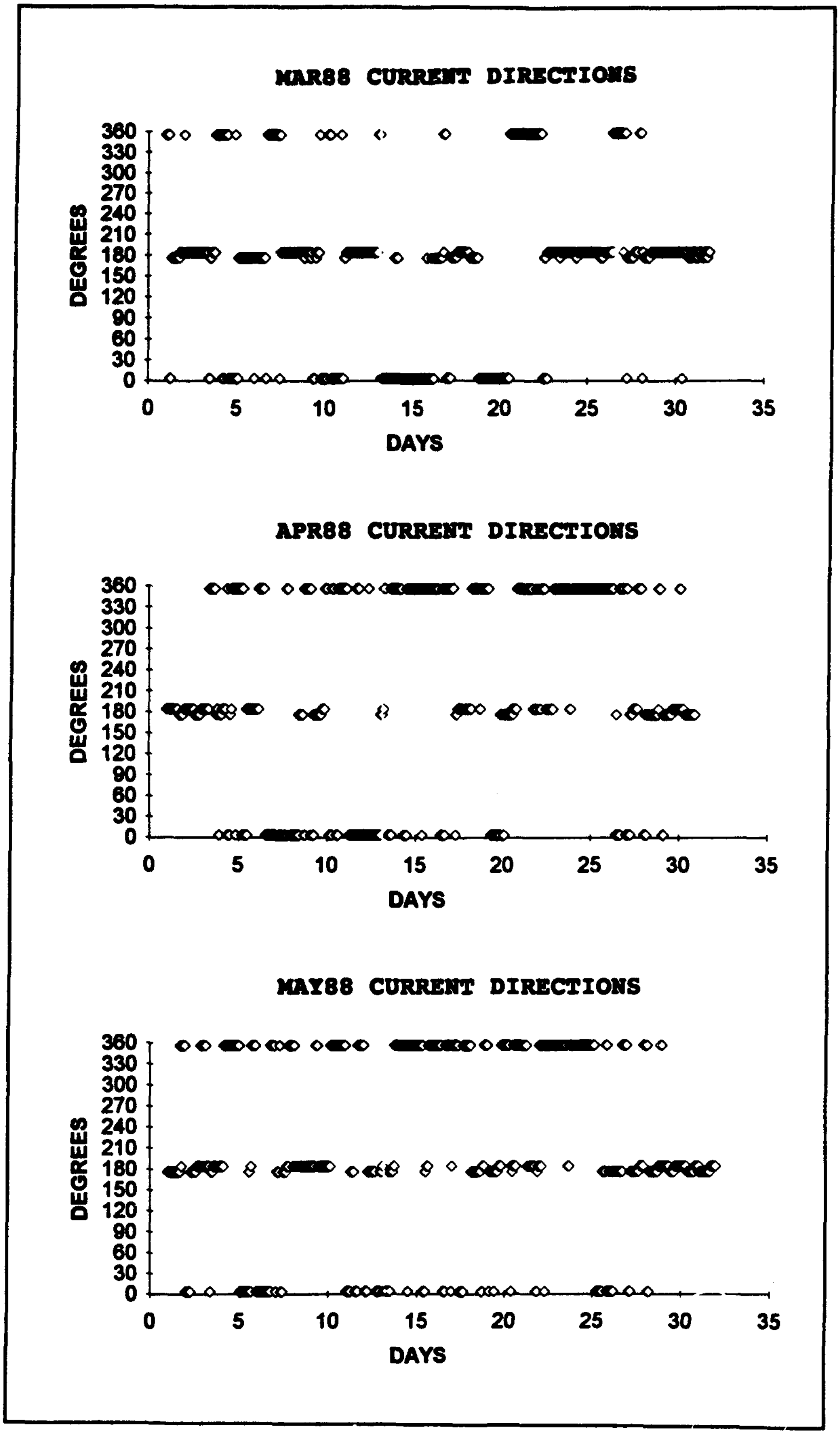
35
DAYS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150
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60
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10
15
20
25
30
35
DAYS
APR88 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
5
10
15
20
25
30
35
DAYS
MAY88 CURRENT DIRECTIONS
DEGREES
360
330
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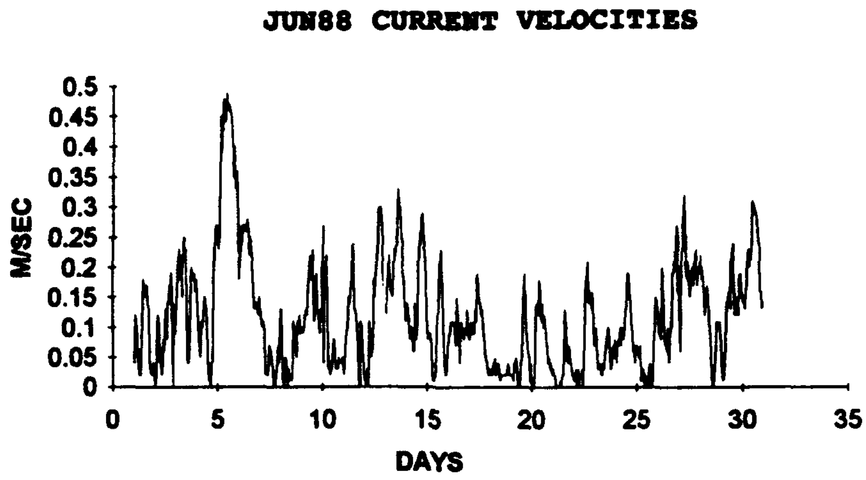
DAYS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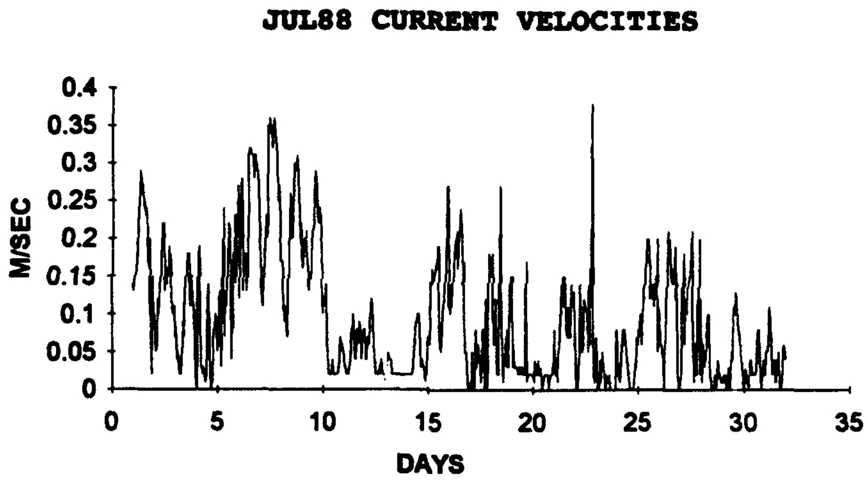
DAYS


JUL88 CURRENT VELOCITIES
M/SEC
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10
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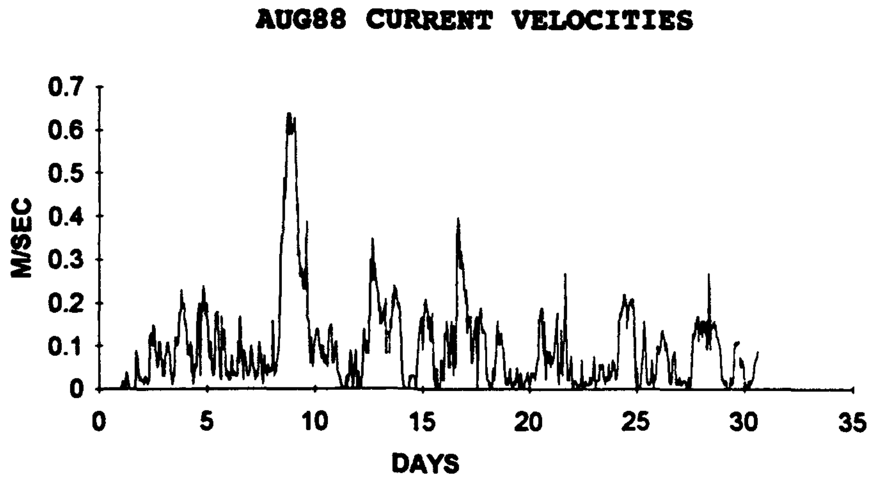
DAYS


AUG88 CURRENT VELOCITIES
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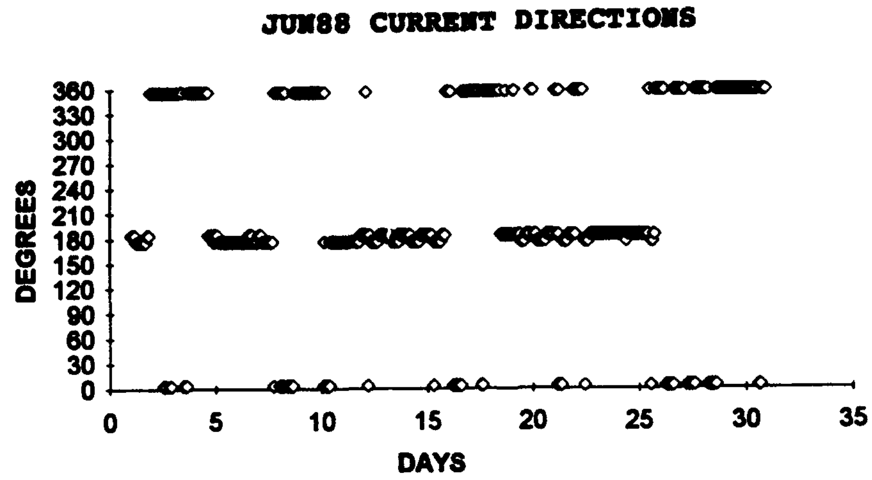
DAYS



JUN88 CURRENT DIRECTIONS
DEGREES
360
330
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180
150
120
90
60
30
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0
5
10
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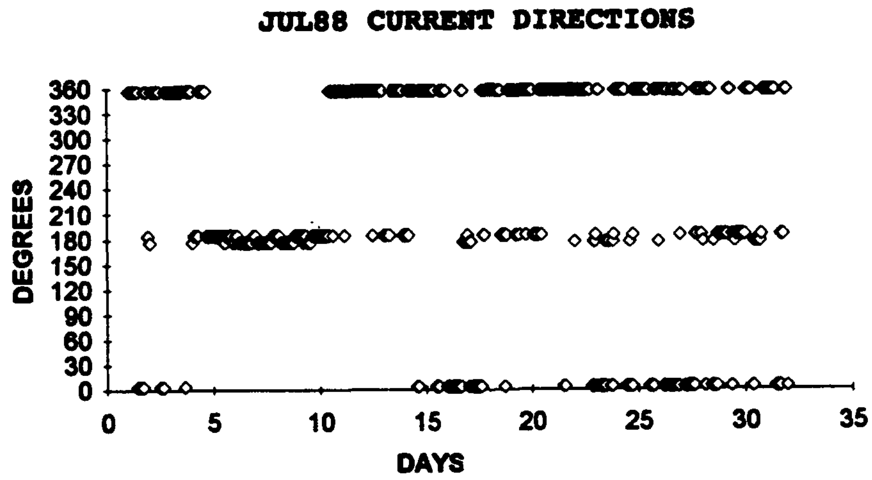
20
25
30
35
DAYS



JUL88 CURRENT DIRECTIONS
DEGREES
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60
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10
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30
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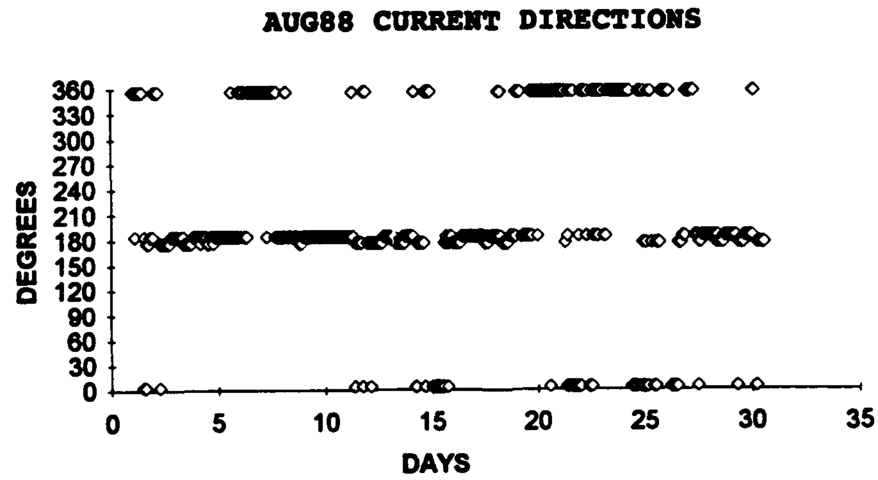
DAYS



AUG88 CURRENT DIRECTIONS
DEGREES
360
330
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270
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180
150
120
90
60
30
0
0
5
10
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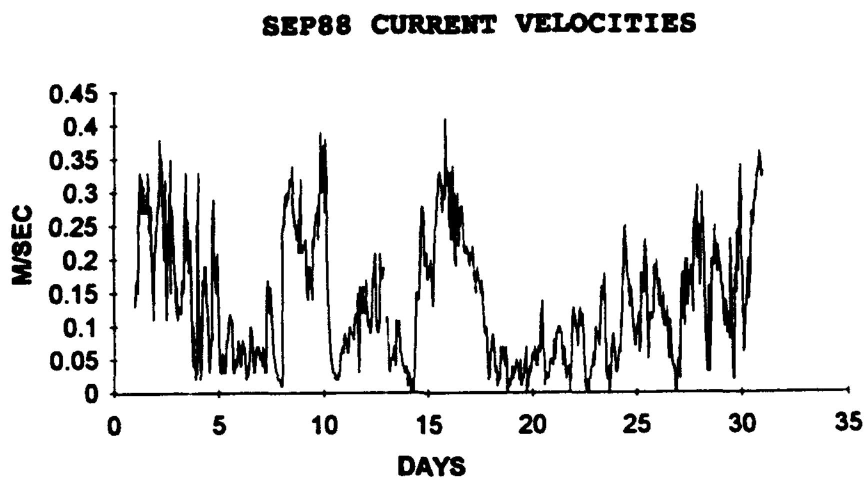
20
25
30
35
DAYS


SEP88 CURRENT VELOCITIES
M/SEC
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0.15
0.1
0.05
0
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5
10
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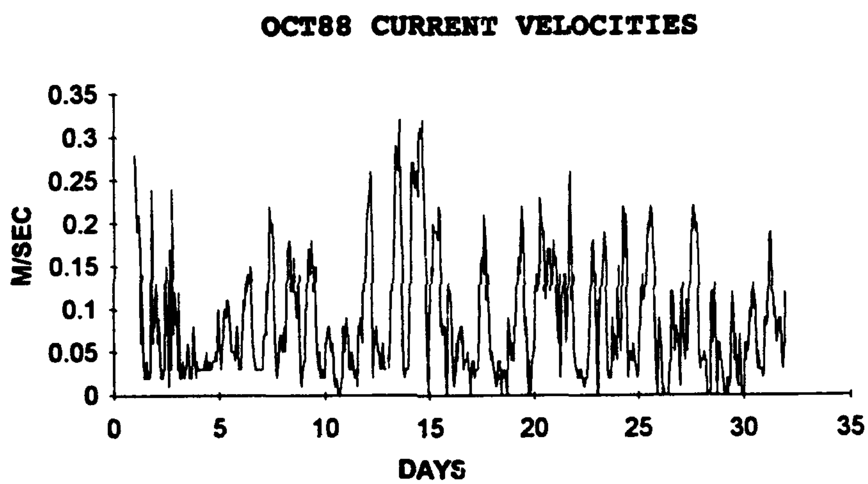
20
25
30
35
DAYS


OCT88 CURRENT VELOCITIES
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0.05
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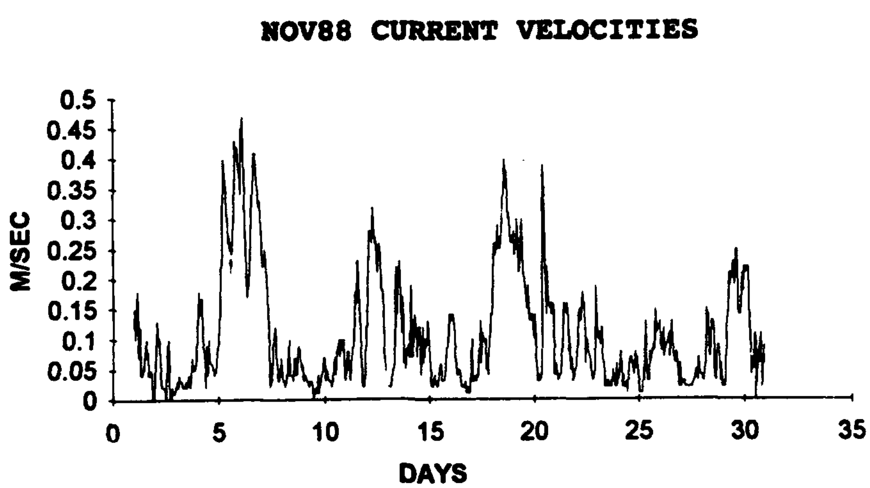
5
10
15
20
25
30
35
DAYS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0
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5
10
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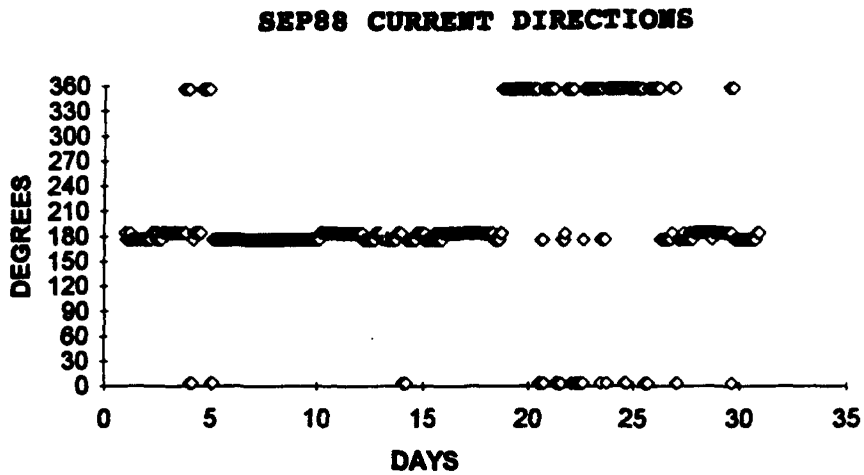
20
25
30
35
DAYS


SEP88 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
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10
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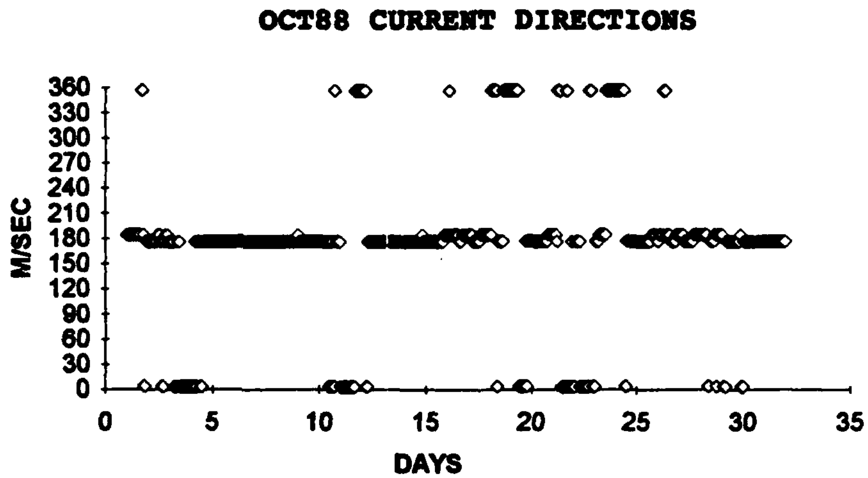
20
25
30
35
DAYS


OCT88 CURRENT DIRECTIONS
M/SEC
360
330
300
270
240
210
180
150
120
90
60
30
0
0
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10
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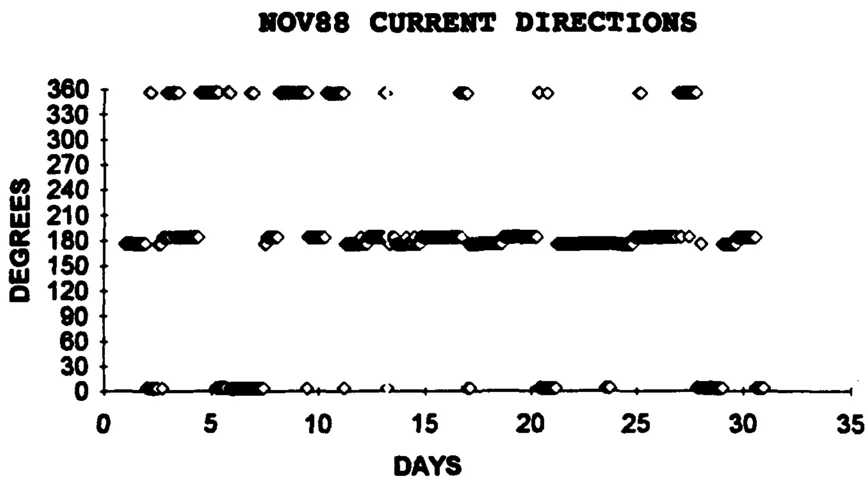
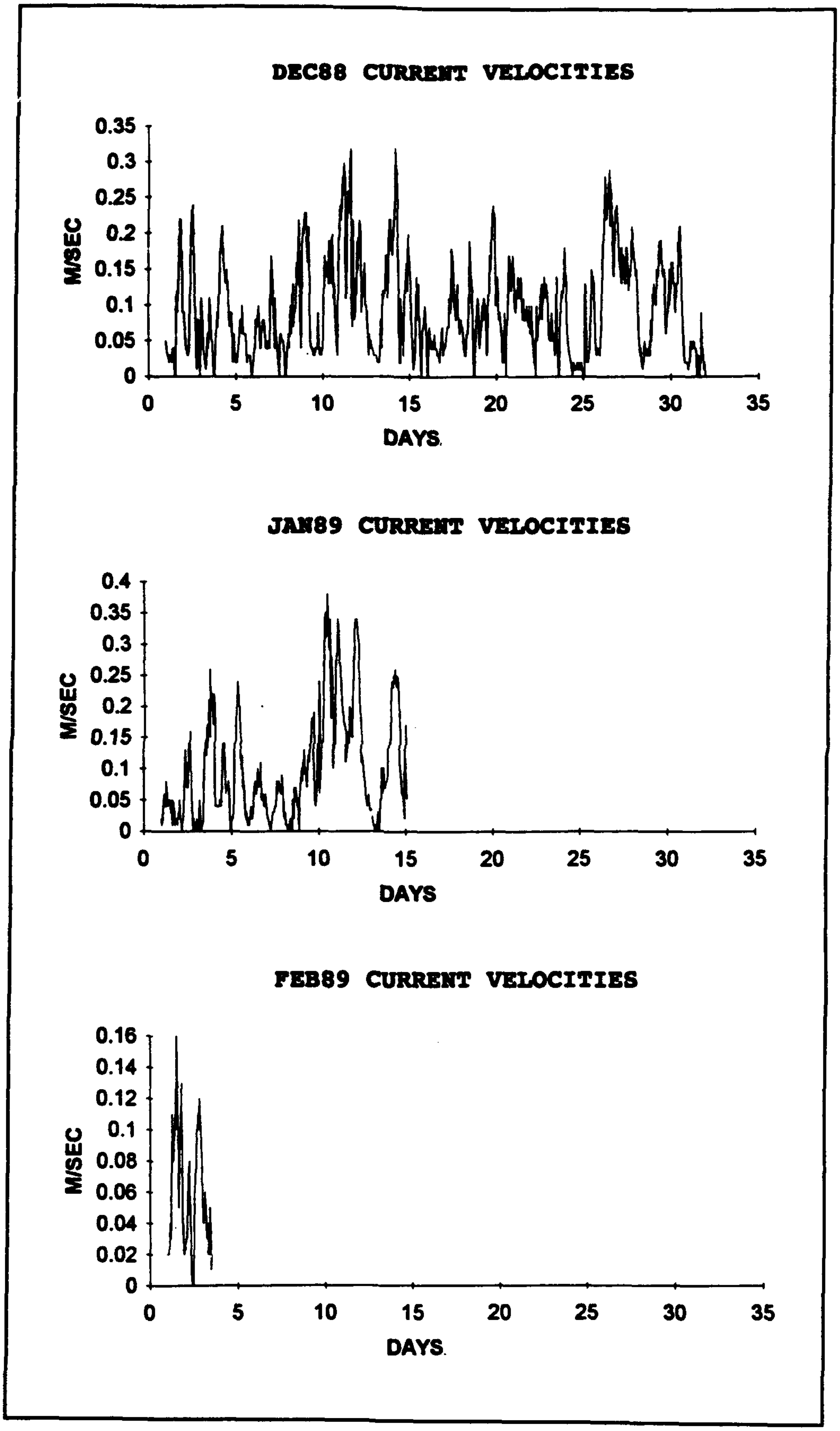
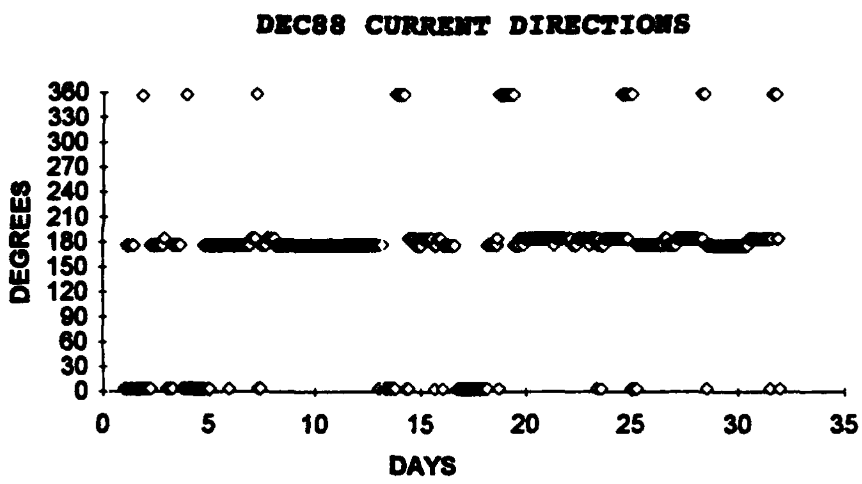
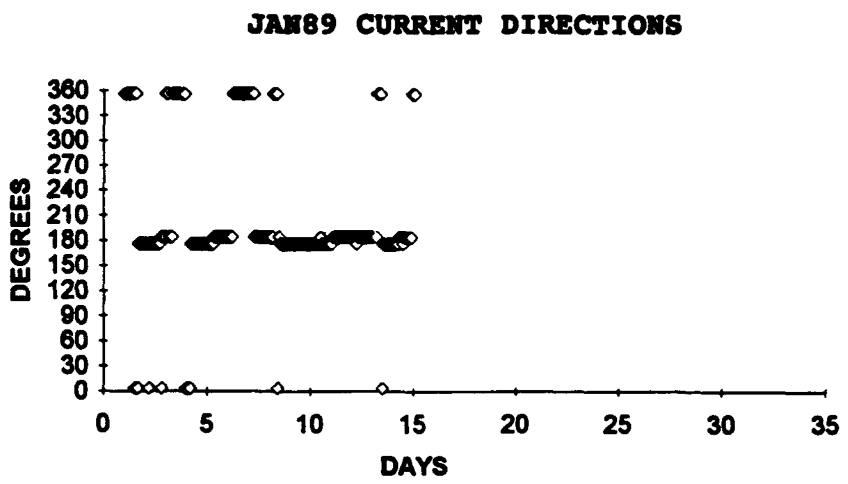
20
25
30
35
DAYS


NOV88 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
5
10
15
20
25
30
35
DAYS

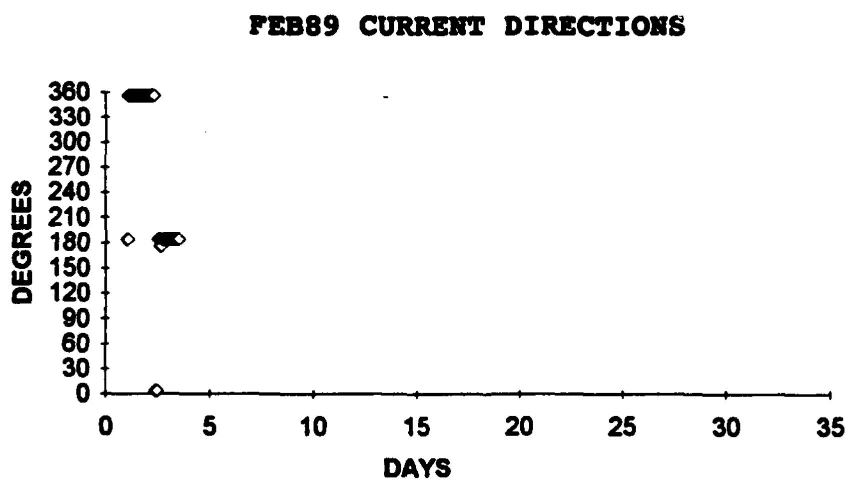

DEC88 CURRENT VELOCITIES
M/SEC
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
DAYS
JAN89 CURRENT VELOCITIES
M/SEC
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
5
10
15
20
25
30
35
DAYS
FEB89 CURRENT VELOCITIES
M/SEC
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
5
10
15
20
25
30
35
DAYS



DEC88 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
5
10
15
20
25
30
35
DAYS

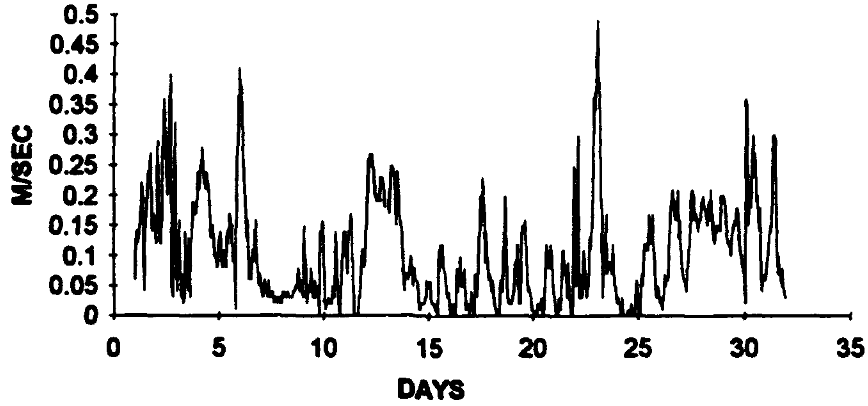


JAN89 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
5
10
15
20
25
30
35
DAYS

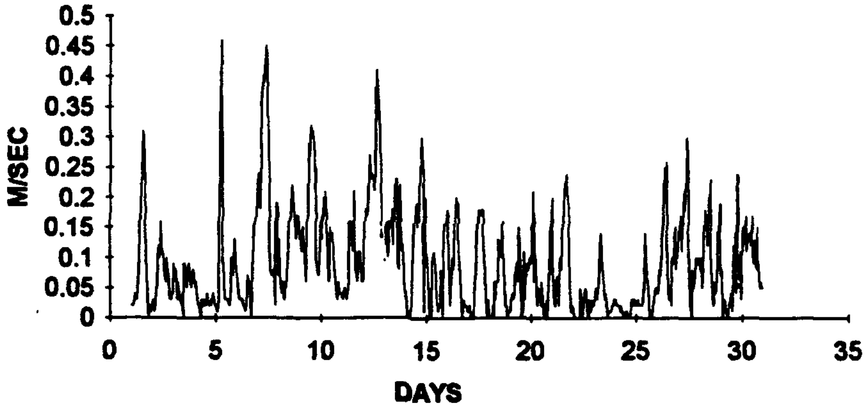


FEB89 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
5
10
15
20
25
30
35
DAYS

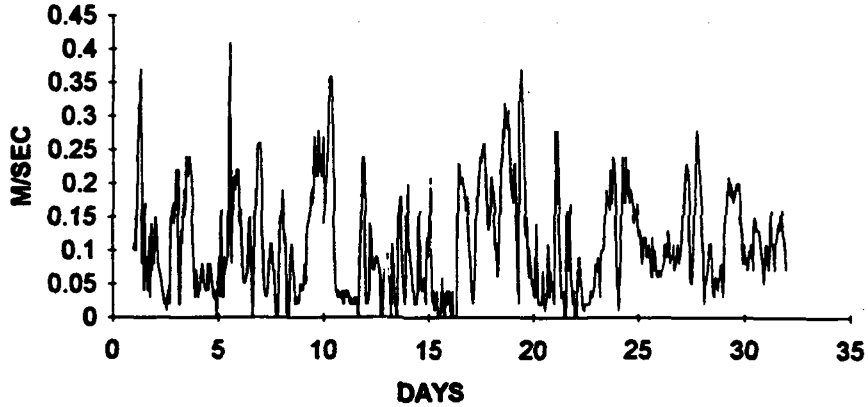
MAR89 CURRENT VELOCITIES



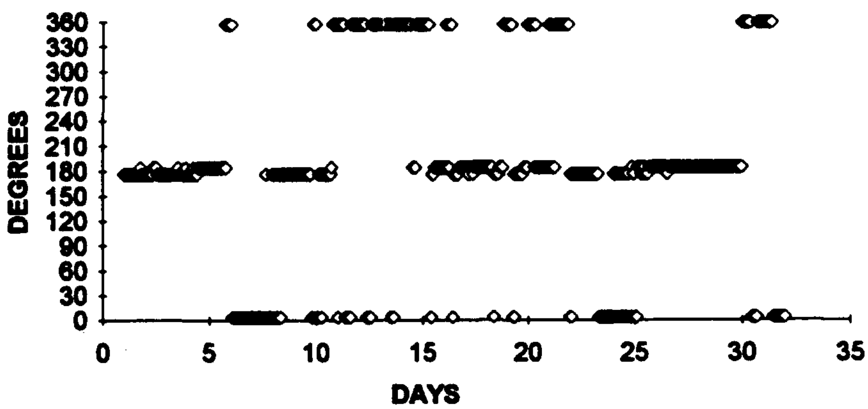
APR89 CURRENT VELOCITIES



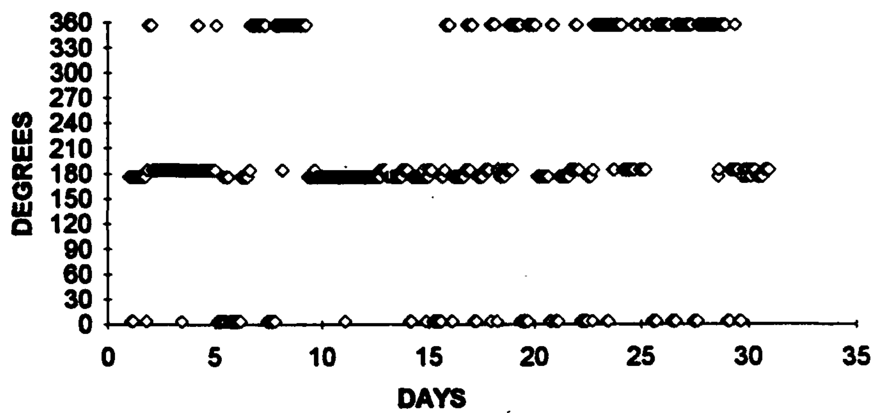
MAY89 CURRENT VELOCITIES



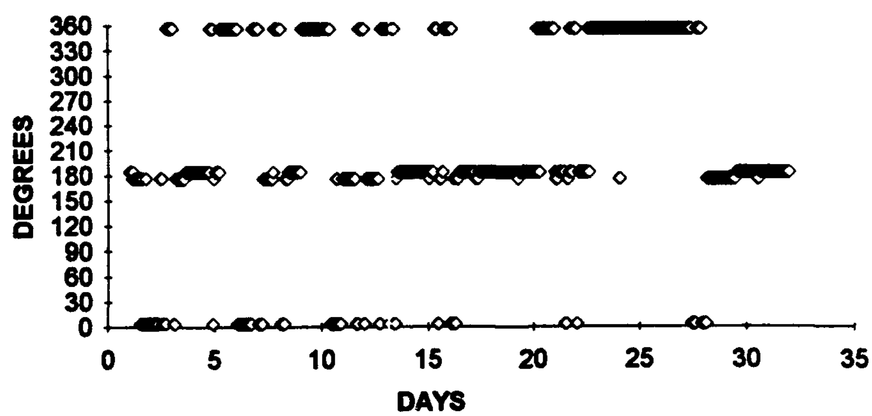
MAR89 CURRENT DIRECTIONS

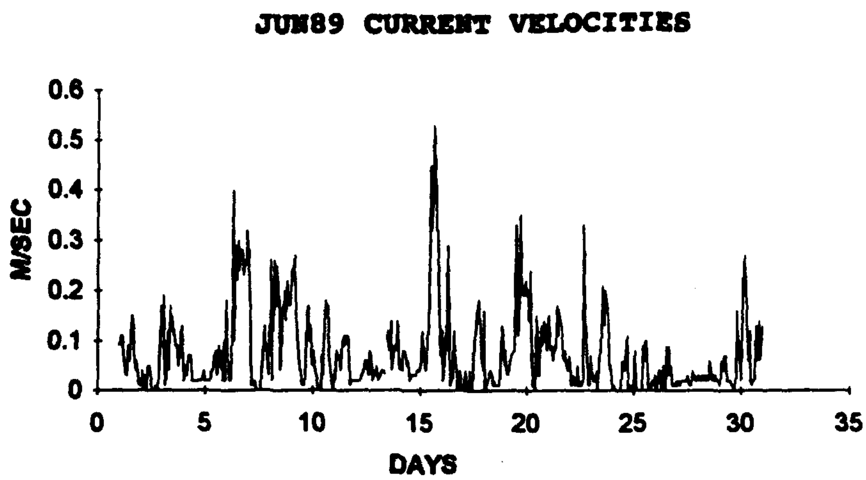


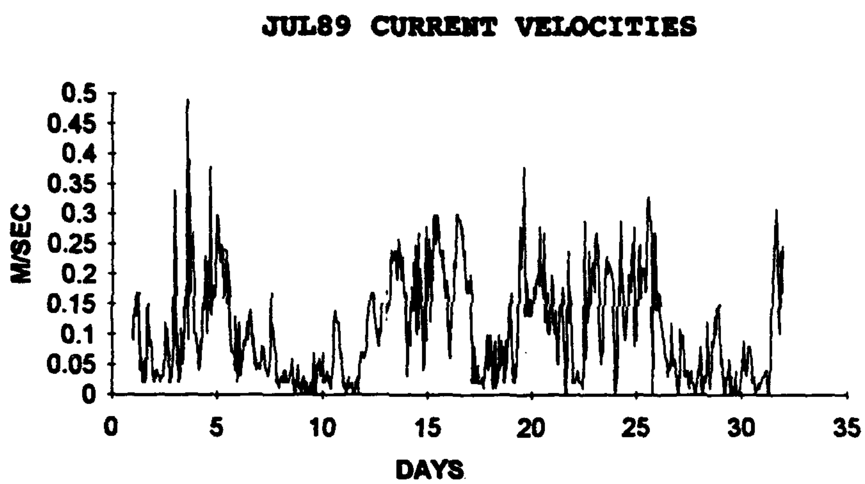
APR89 CURRENT DIRECTIONS

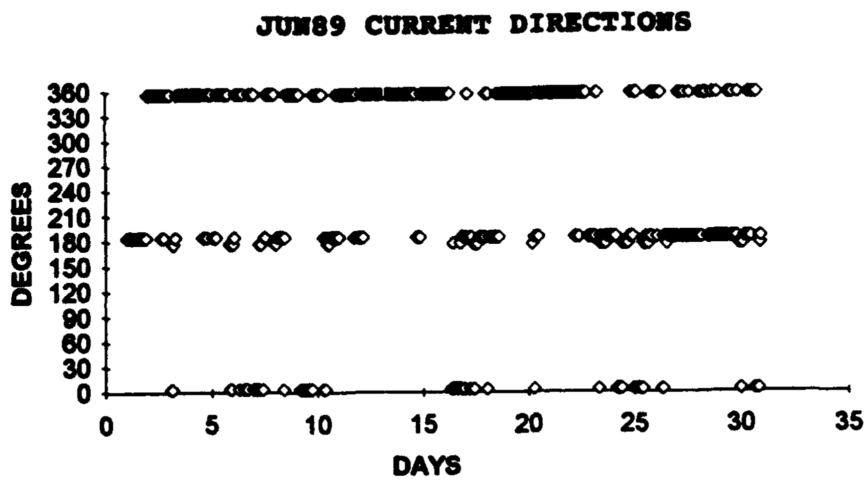


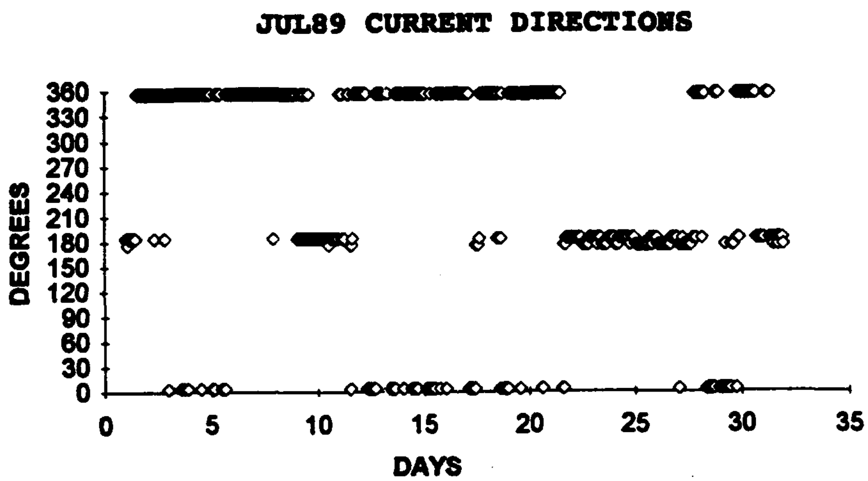
MAY89 CURRENT DIRECTIONS




JUN89 CURRENT VELOCITIES
0.6
0.5
0.4
0.3
0.2
0.1
0
M/SEC
0
5
10
15
20
25
30
35
DAYS

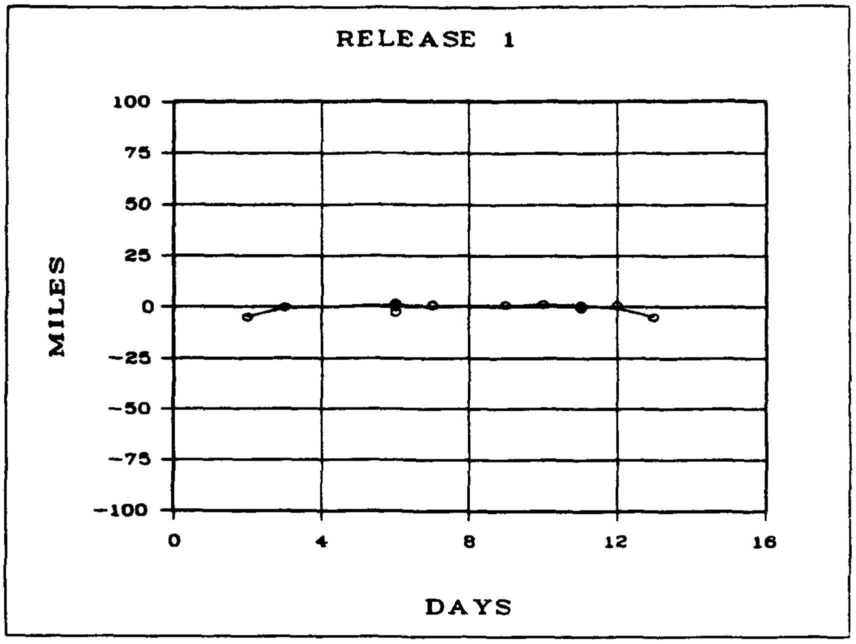

JUL89 CURRENT VELOCITIES
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
M/SEC
0
5
10
15
20
25
30
35
DAYS


JUN89 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
5
10
15
20
25
30
35
DAYS

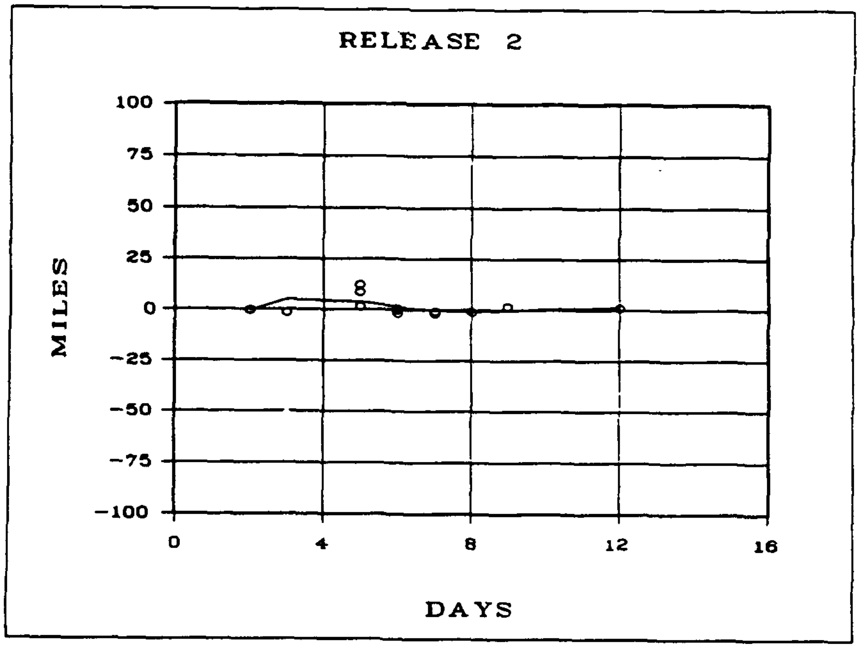

JUL89 CURRENT DIRECTIONS
DEGREES
360
330
300
270
240
210
180
150
120
90
60
30
0
0
5
10
15
20
25
30
35
DAYS

Appendix E
Representation of Smoothed Recovery Patterns

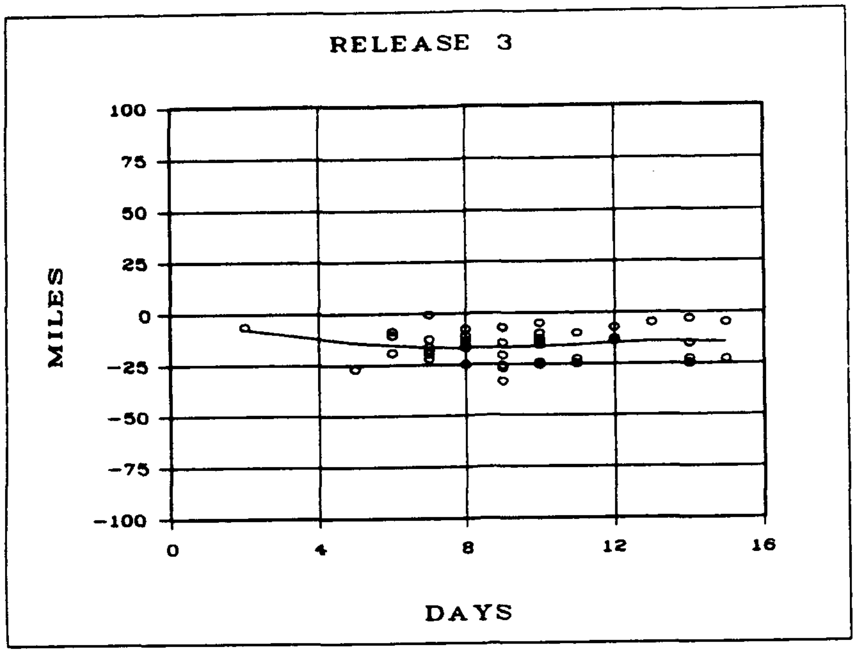
A smoothed curve, fit to the initial SBD recoveries, is taken as a measure of the deterministic signal from the central cloud of SBD's returned in 5-day segments. Each release episode has been treated separately. The release dates for each episode are in Table 2. The elapsed time, shown on the horizontal axis, was rounded to the nearest day before the figures were plotted. The rounding and the scale of the displacements shown on the vertical axes do not interfere with the fitting, nor do they prevent independent visual impressions of the "randomness" of the observed deviations from these trends. These graphical limitations should be noted, however, because the smoothing and the scale of the plots result in many superposed recovery points. If unrecognized, these superimposed points could be interpreted as indicating fewer recovery points than actually existed and went into the final analysis.



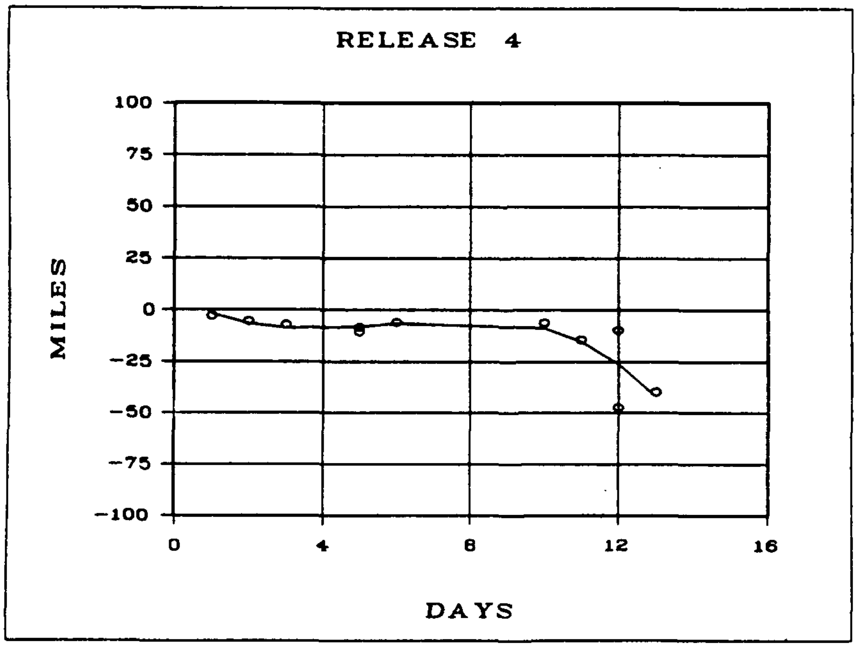
RELEASE 1
MILES
DAYS
100
75
50
25
0
-25
-50
-75
-100
0
4
8
12
16



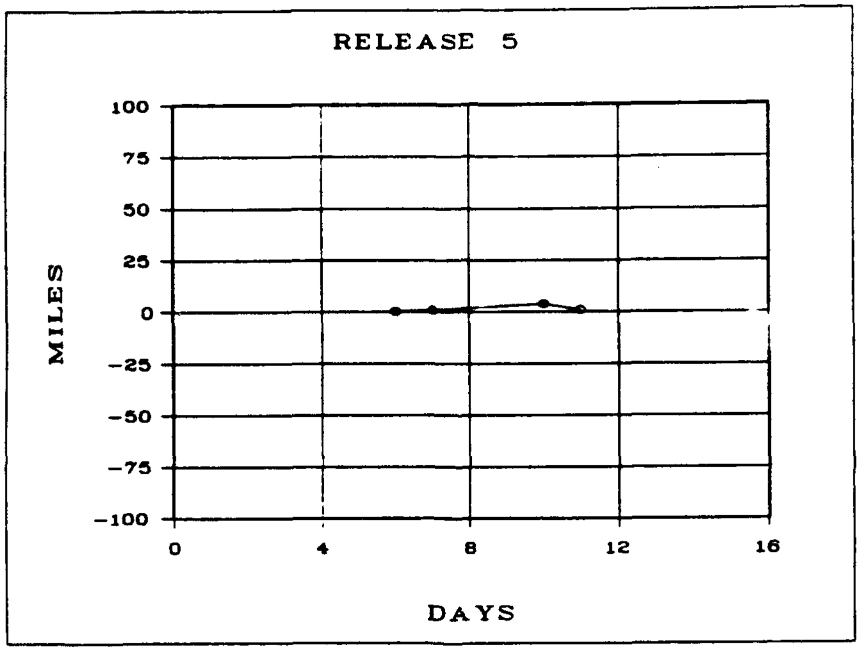
RELEASE 2
MILES
DAYS
100
75
50
25
0
-25
-50
-75
-100
0
4
8
12
16

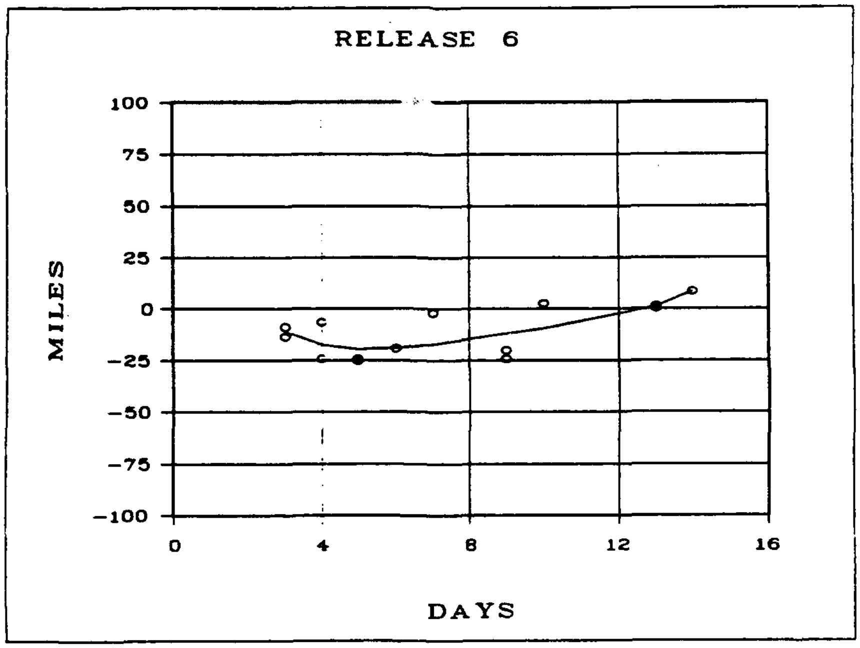


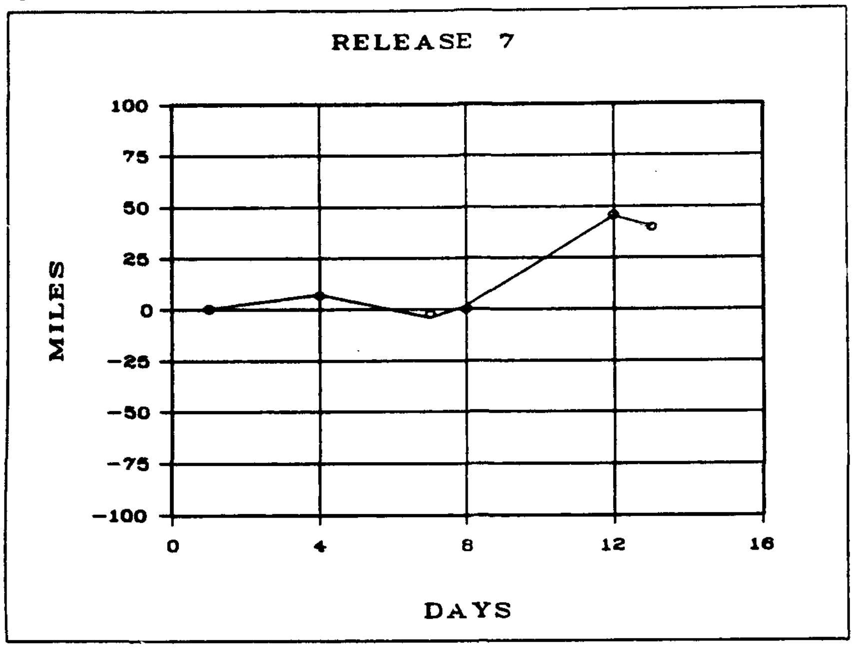
RELEASE 3
100
75
50
25
0
-25
-50
-75
-100
MILES
0
4
8
12
16
DAYS

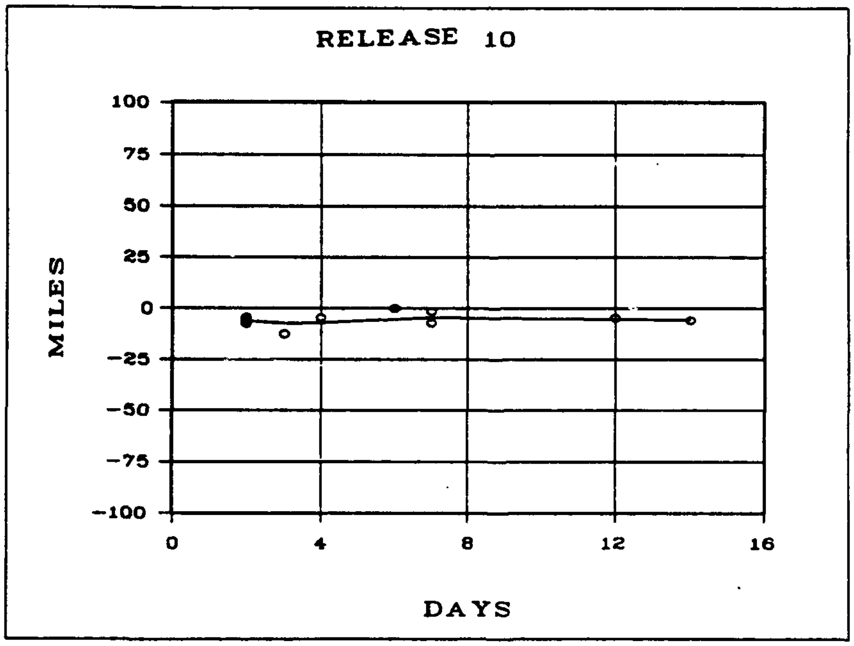


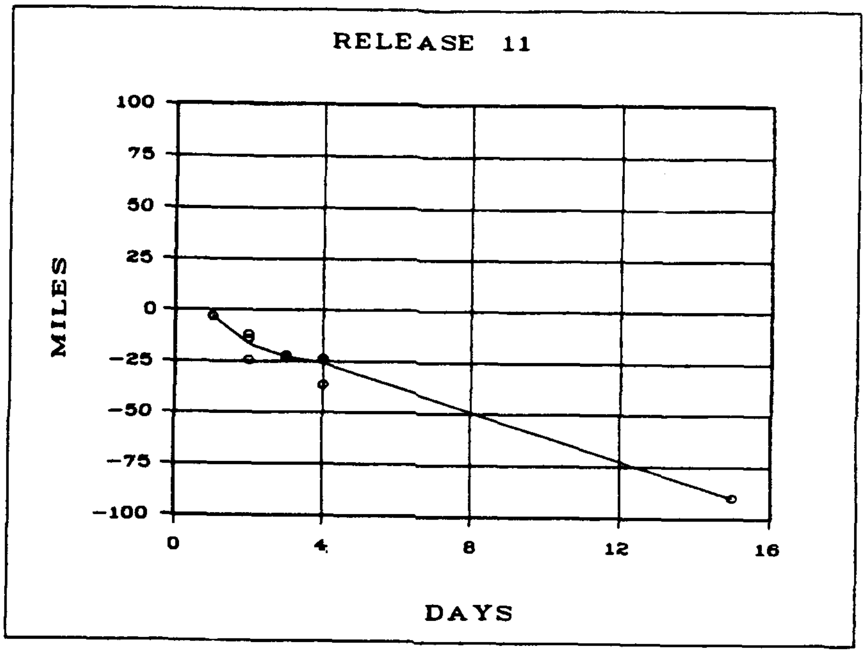
RELEASE 4
100
75
50
25
0
-25
-50
-75
-100
MILES
0
4
8
12
16
DAYS

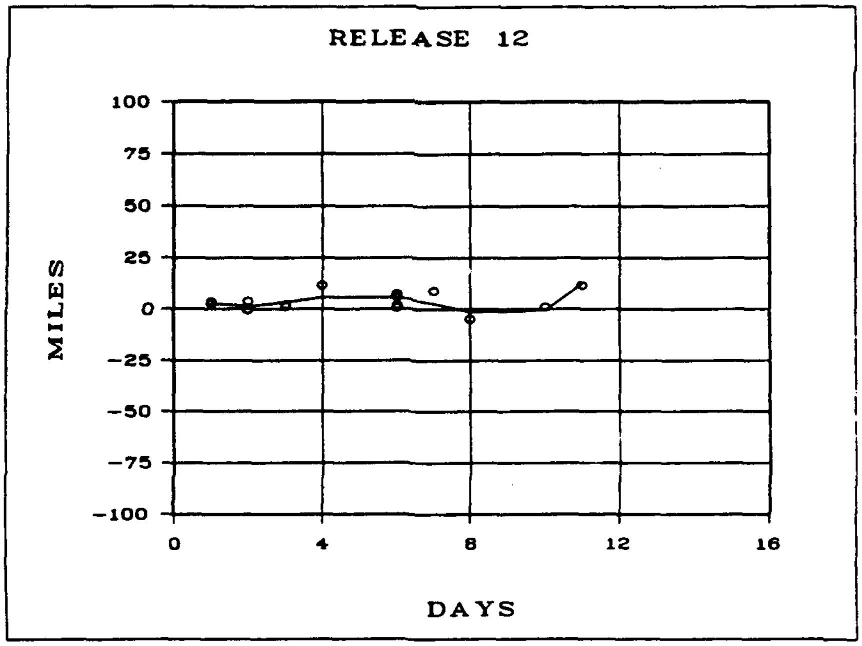

RELEASE 5
100
75
50
25
0
-25
-50
-75
-100
MILES
0
4
8
12
16
DAYS

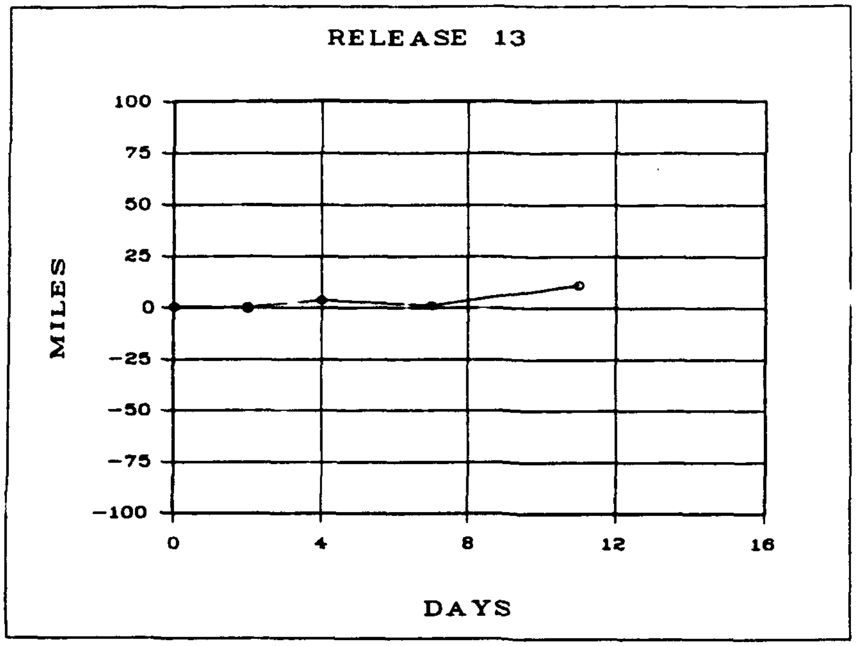

RELEASE 6
100
75
50
25
0
-25
-50
-75
-100
MILES
0
4
8
12
16
DAYS


RELEASE 7
MILES
DAYS
100
75
50
25
0
-25
-50
-75
-100
0
4
8
12
16

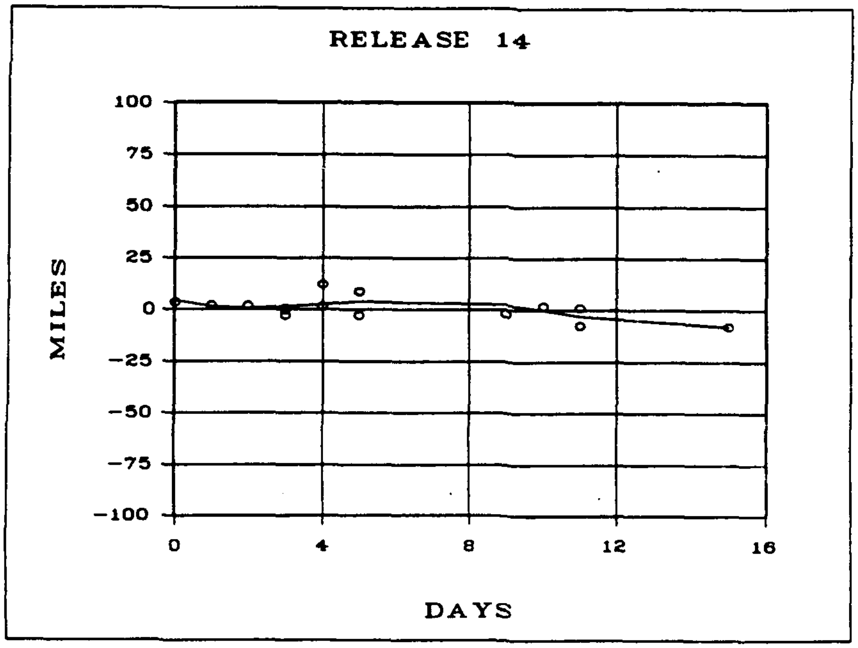

RELEASE 10
MILES
DAYS
100
75
50
25
0
-25
-50
-75
-100
0
4
8
12
16


RELEASE 11
100
75
50
25
0
-25
-50
-75
-100
MILES
0
4
8
12
16
DAYS

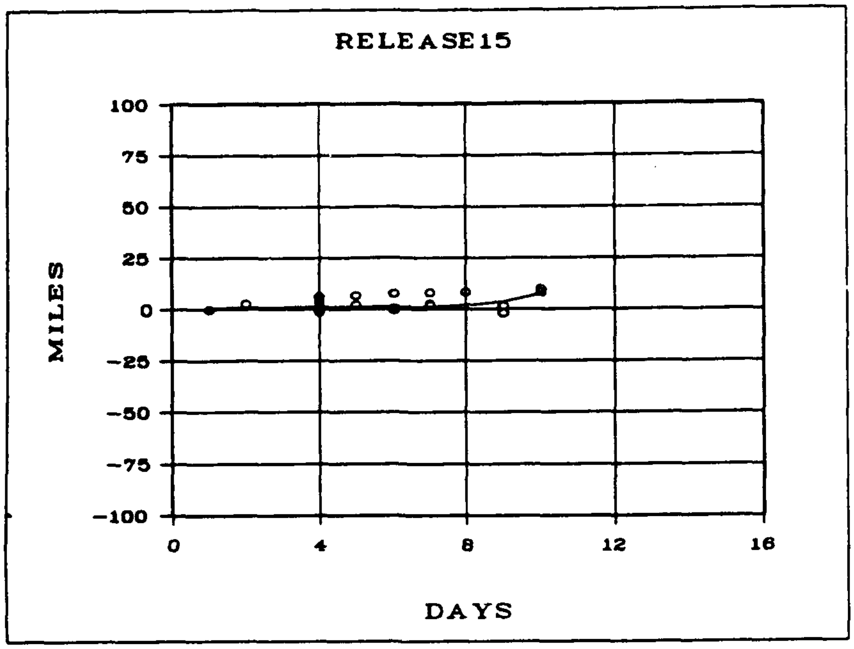

RELEASE 12
100
75
50
25
0
-25
-50
-75
-100
MILES
0
4
8
12
16
DAYS

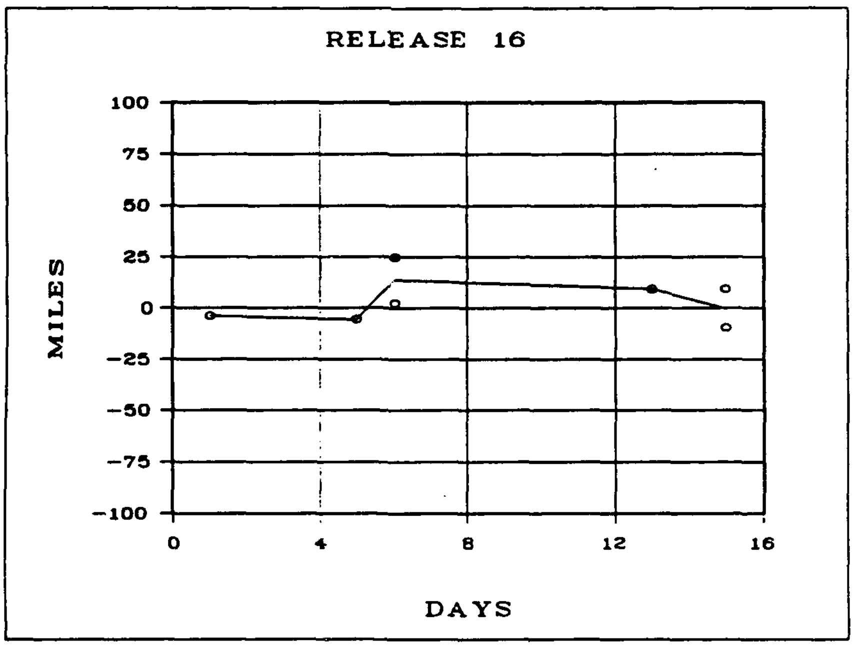


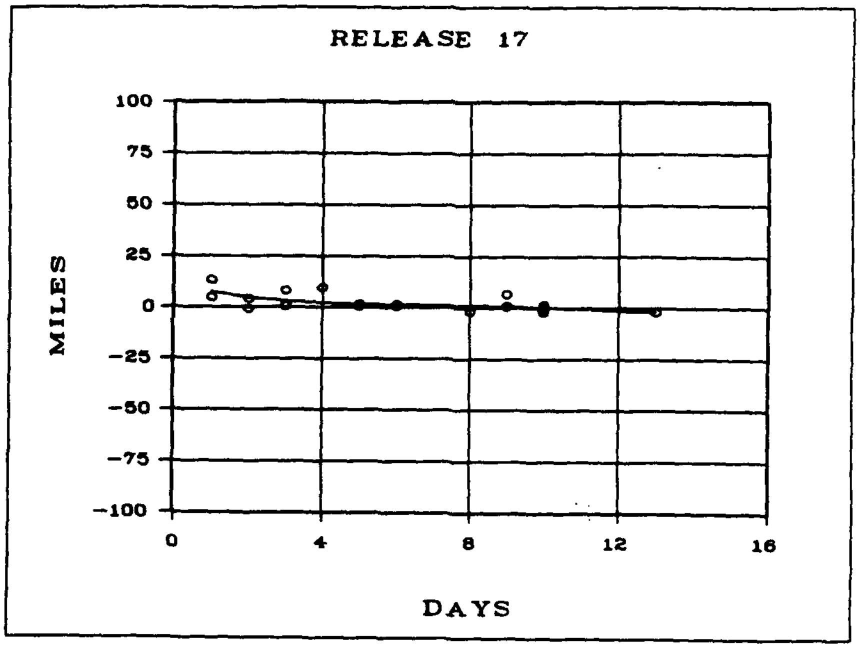
RELEASE 13
MILES
DAYS

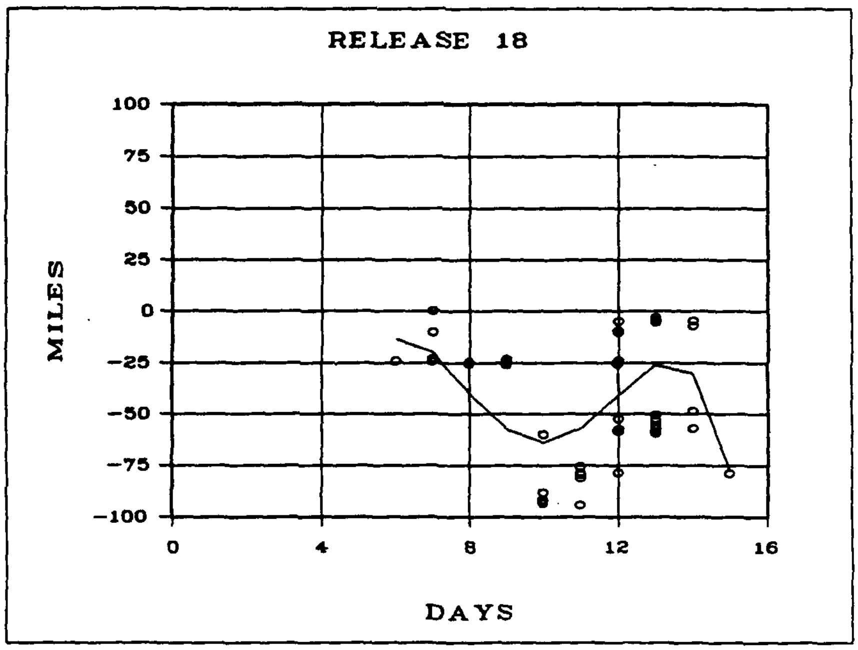


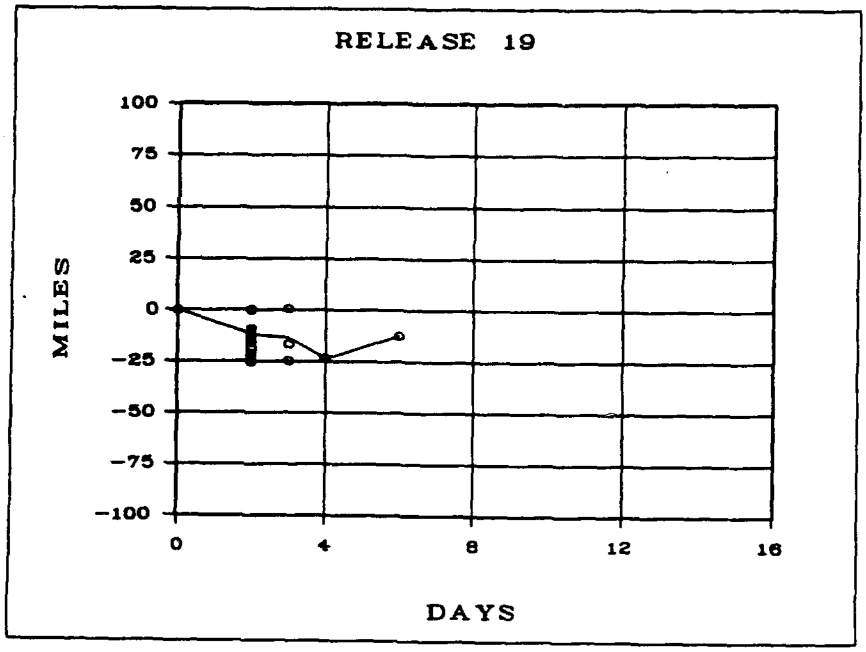
RELEASE 14
MILES
DAYS


RELEASE15
MILES
100
75
50
25
0
-25
-50
-75
-100
0
4
8
12
16
DAYS


RELEASE 16
MILES
100
75
50
25
0
-25
-50
-75
-100
0
4
8
12
16
DAYS

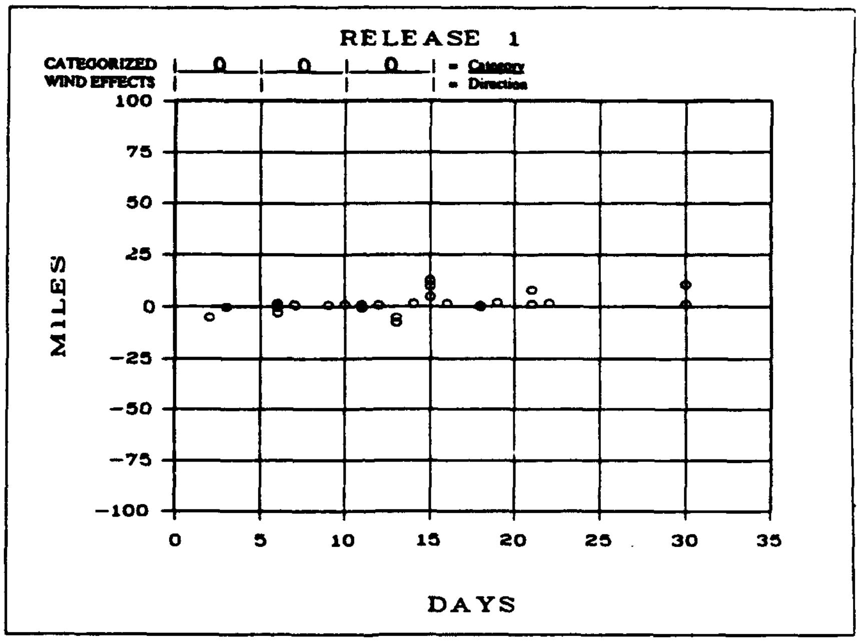

RELEASE 17
100
75
50
25
0
-25
-50
-75
-100
MILES
0
4
8
12
16
DAYS

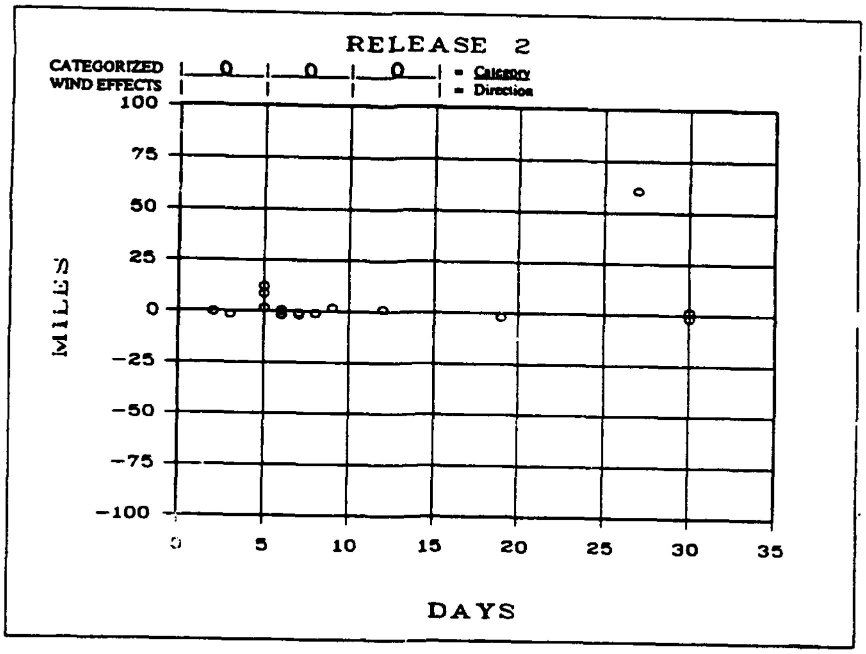

RELEASE 18
100
75
50
25
0
-25
-50
-75
-100
MILES
0
4
8
12
16
DAYS

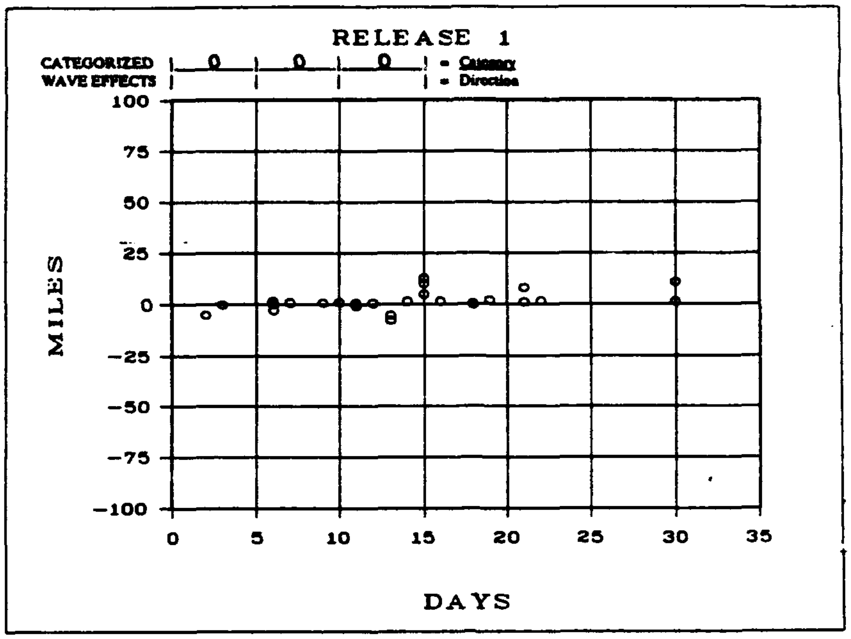

RELEASE 19
100
75
50
25
0
-25
-50
-75
-100
MILES
0
4
8
12
16
DAYS

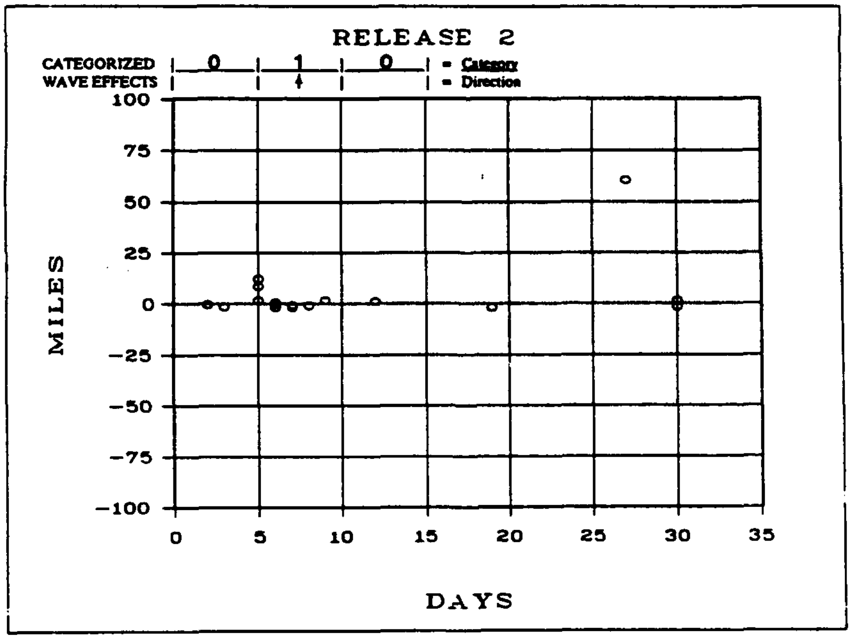
Appendix F
Plots Showing Categorized Wind-Driven and Wave-Driven Effects

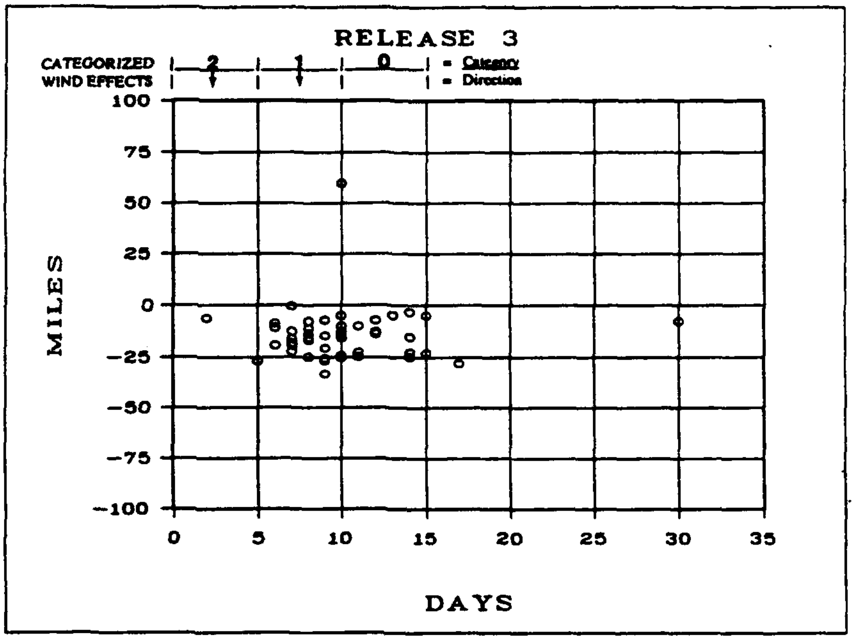
The categorized effects given in the upper left of each plot match values in Tables 6 and 7 of the report. The arrows below the categories indicate the direction of wind- or wave-driven motion. The elapsed time, shown on the horizontal axis, was rounded to the nearest day before the figures were plotted. This rounding and the scale of the displacements shown on the vertical axes do not affect the categorization of driving forces or interfere with the impression these figures provide of the response to the separate forces. These graphical limitations should be noted, however, because the smoothing and scale of the plots do result in many superposed recovery points which, if unrecognized, could give a false impression of fewer data points than actually went into the analysis. The contingency table in Chapter 6 combines and summarizes the results from all the first 19 SBD release episodes.


RELEASE 1
CATEGORIZED
WIND EFFECTS
0
0
0
= Category
= Direction
MILES
100
75
50
25
0
-25
-50
-75
-100
0
5
10
15
20
25
30
35
DAYS

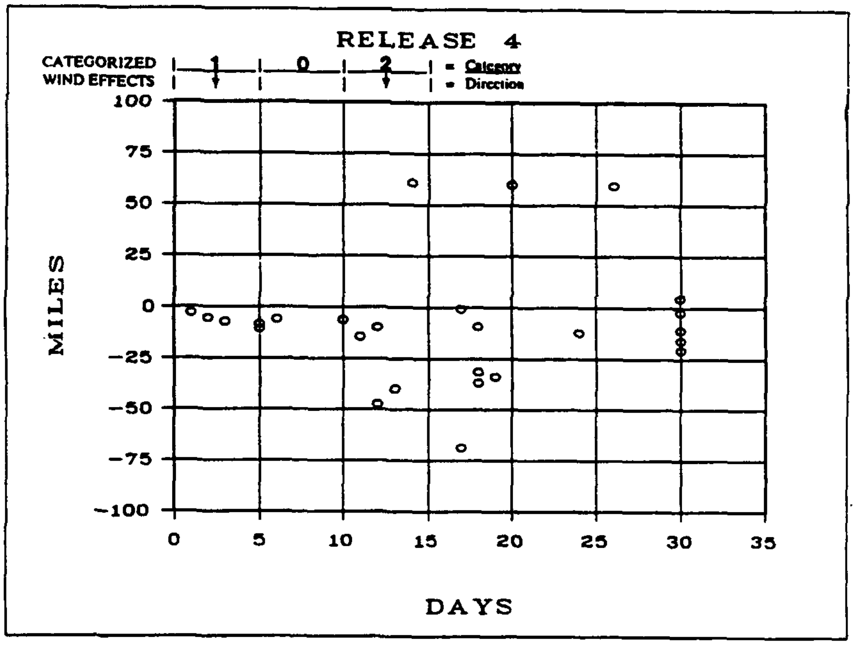

RELEASE 2
CATEGORIZED
WIND EFFECTS
0
0
0
= Category
= Direction
MILES
100
75
50
25
0
-25
-50
-75
-100
0
5
10
15
20
25
30
35
DAYS


RELEASE 1
CATEGORIZED
WAVE EFFECTS
0
0
0
= Category
= Direction
MILES
DAYS

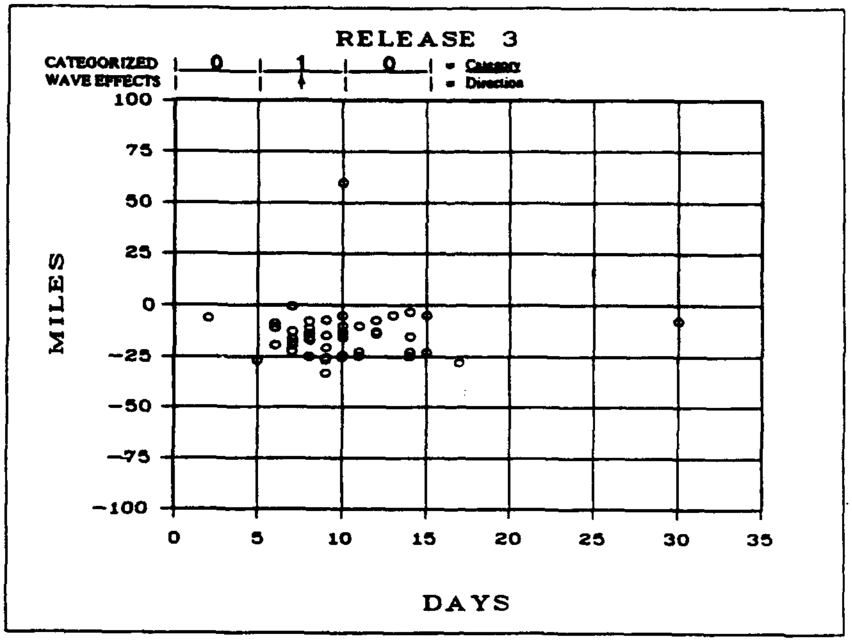

RELEASE 2
CATEGORIZED
WAVE EFFECTS
0
1
0
= Category
= Direction
MILES
DAYS

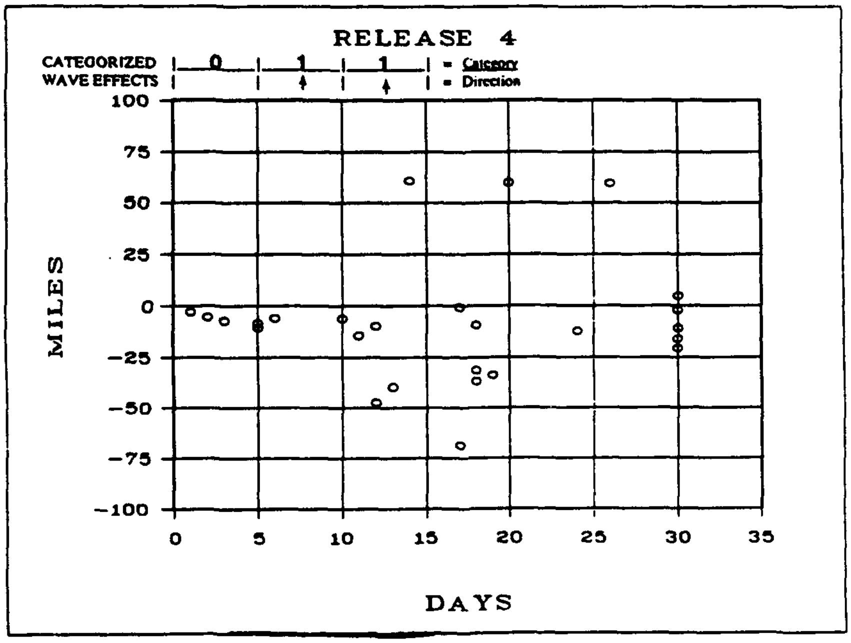


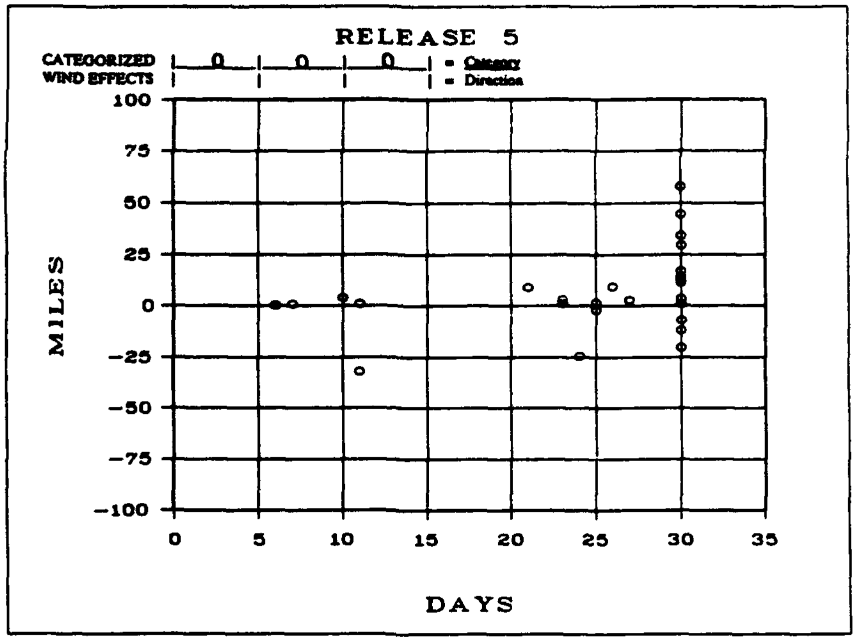
RELEASE 3
CATEGORIZED WIND EFFECTS
2
1
0
= Category
= Direction
MILES
100
75
50
25
0
−25
−50
−75
−100
0
5
10
15
20
25
30
35
DAYS



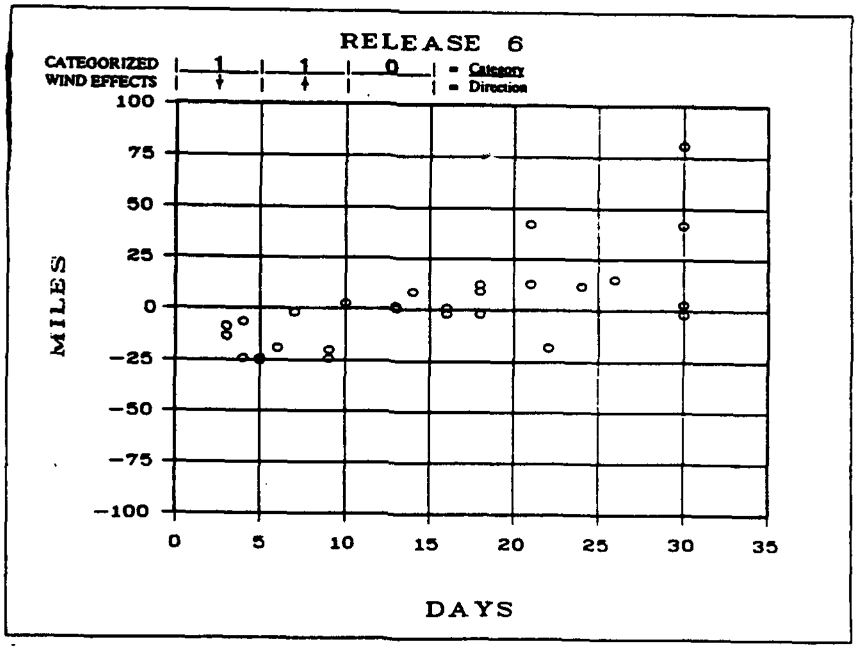
RELEASE 4
CATEGORIZED WIND EFFECTS
1
0
2
= Category
= Direction
MILES
100
75
50
25
0
−25
−50
−75
−100
0
5
10
15
20
25
30
35
DAYS


RELEASE 3
CATEGORIZED
WAVE EFFECTS
0
1
0
= Category
= Direction
100
75
50
25
0
-25
-50
-75
-100
MILES
0
5
10
15
20
25
30
35
DAYS

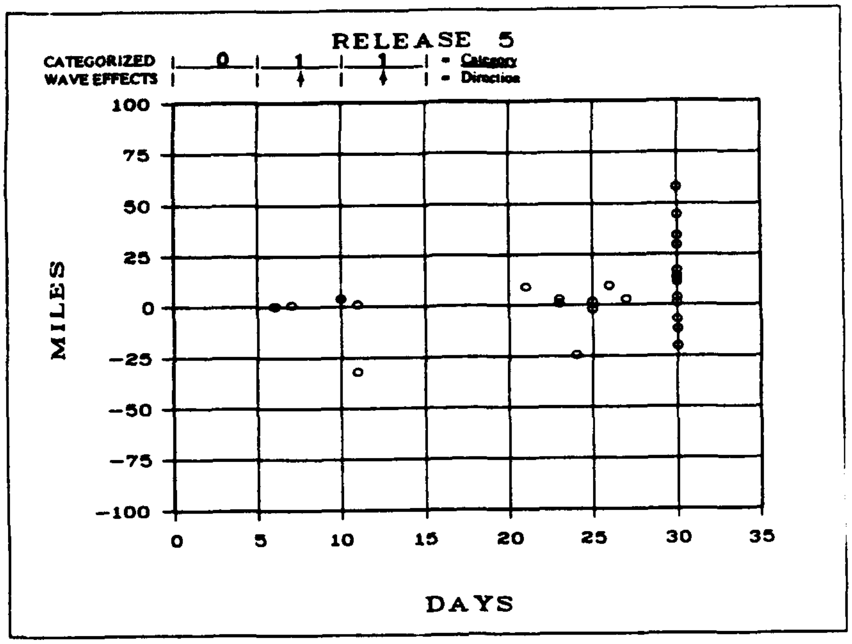

RELEASE 4
CATEGORIZED
WAVE EFFECTS
0
1
1
= Category
= Direction
100
75
50
25
0
-25
-50
-75
-100
MILES
0
5
10
15
20
25
30
35
DAYS

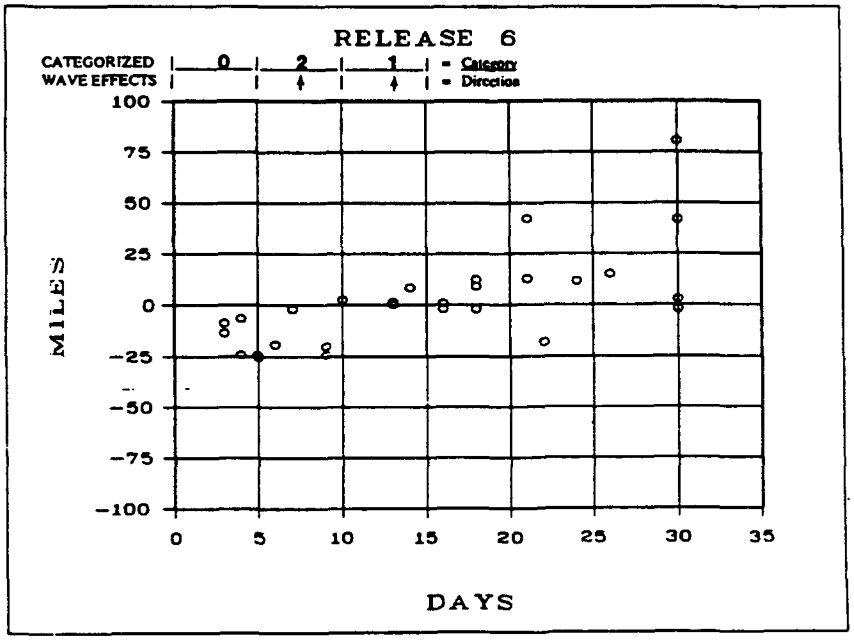


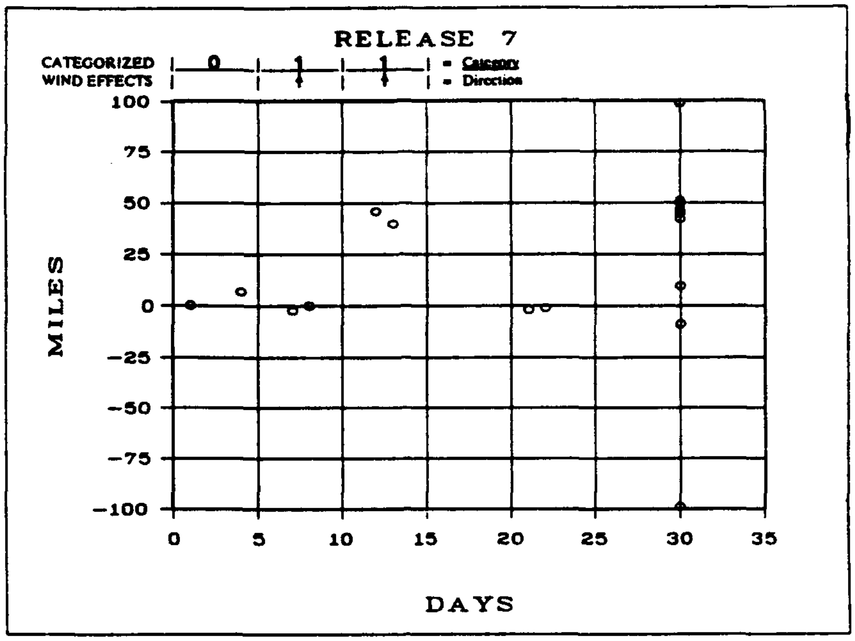
RELEASE 5
CATEGORIZED WIND EFFECTS
0
0
0
= Category
= Direction
100
75
50
25
0
-25
-50
-75
-100
MILES
0
5
10
15
20
25
30
35
DAYS

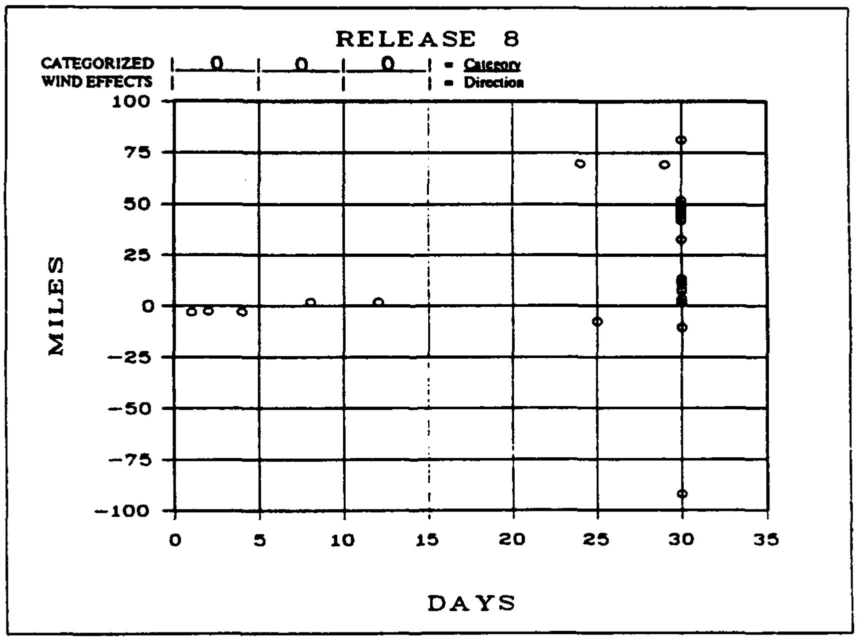


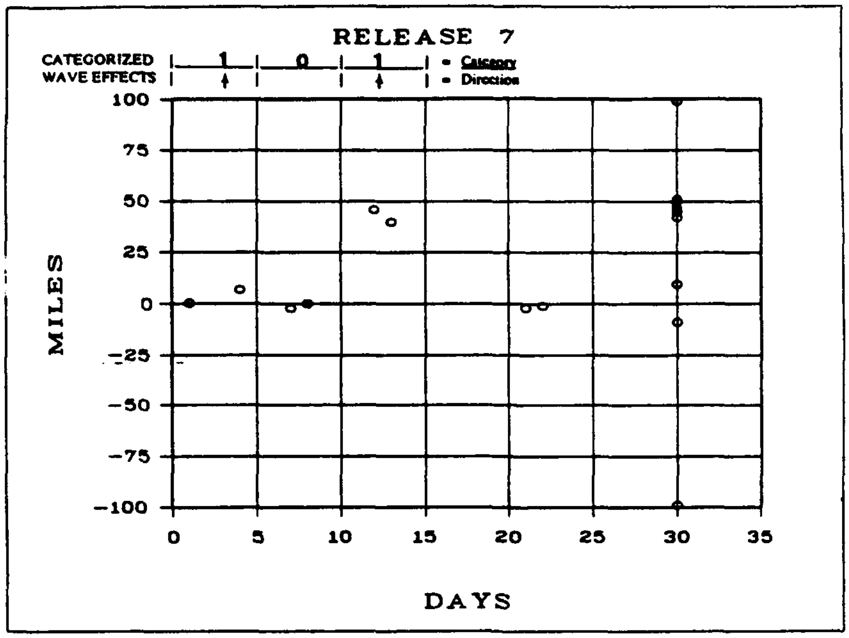
RELEASE 6
CATEGORIZED WIND EFFECTS
1
1
0
= Category
= Direction
100
75
50
25
0
-25
-50
-75
-100
MILES
0
5
10
15
20
25
30
35
DAYS


RELEASE 5
CATEGORIZED WAVE EFFECTS
0
1
1
= Category
= Direction
100
75
50
25
0
-25
-50
-75
-100
MILES
0
5
10
15
20
25
30
35
DAYS


RELEASE 6
CATEGORIZED WAVE EFFECTS
0
2
1
= Category
= Direction
100
75
50
25
0
-25
-50
-75
-100
MILES
0
5
10
15
20
25
30
35
DAYS


RELEASE 7
CATEGORIZED WIND EFFECTS
0
1
1
= Category
= Direction
MILES
100
75
50
25
0
-25
-50
-75
-100
0
5
10
15
20
25
30
35
DAYS


RELEASE 8
CATEGORIZED WIND EFFECTS
0
0
0
= Category
= Direction
MILES
100
75
50
25
0
-25
-50
-75
-100
0
5
10
15
20
25
30
35
DAYS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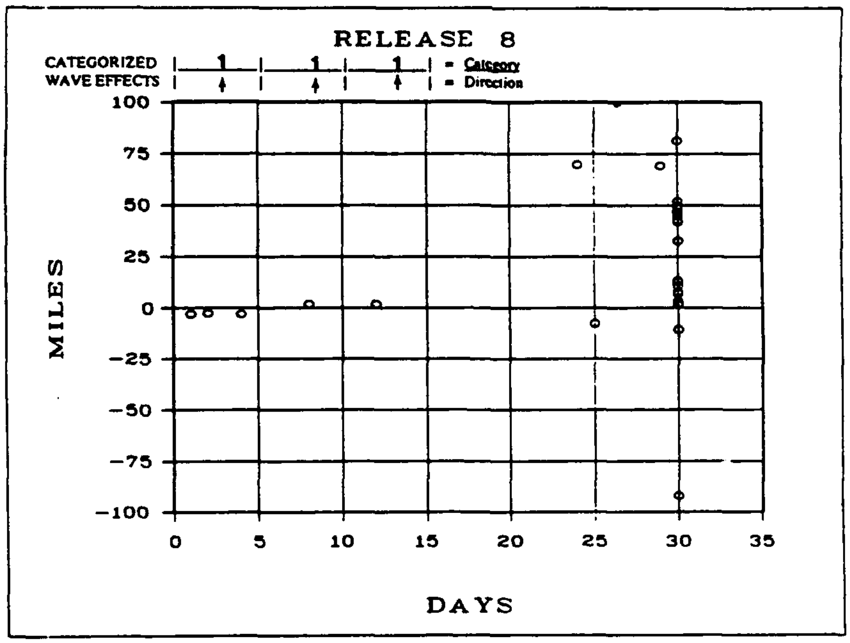
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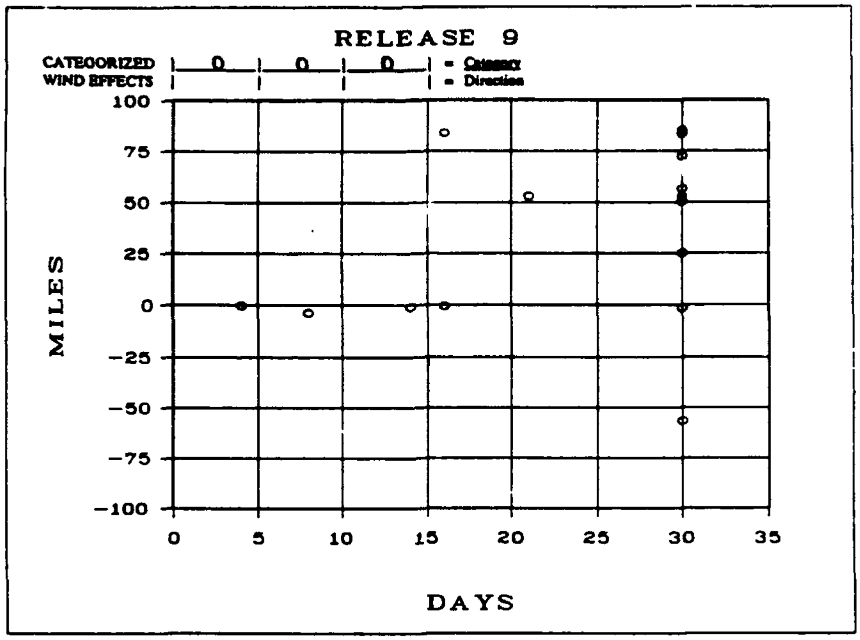
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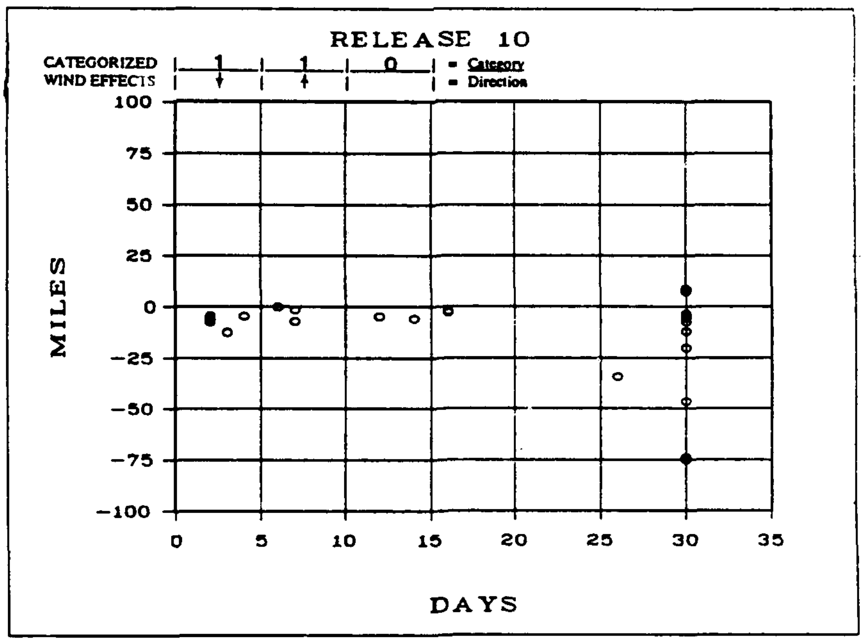
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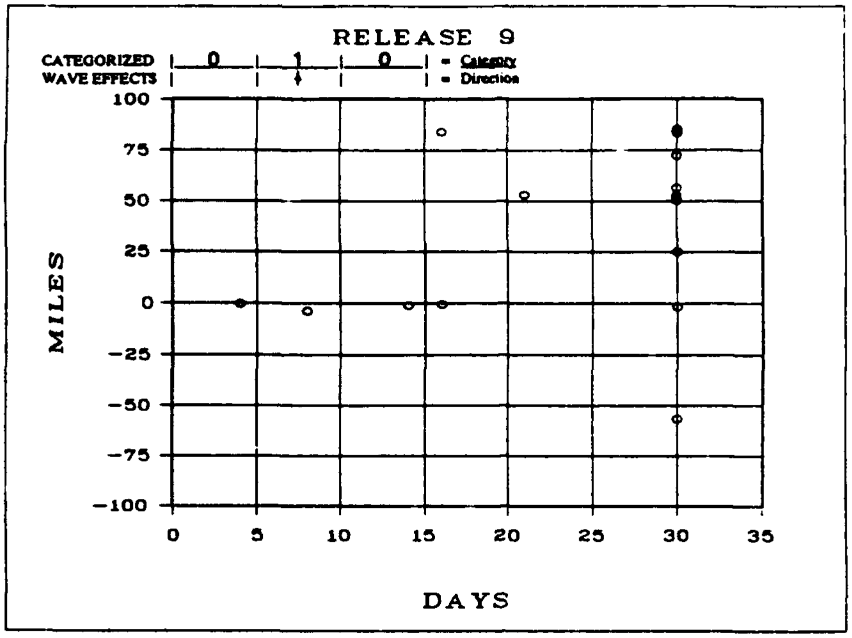
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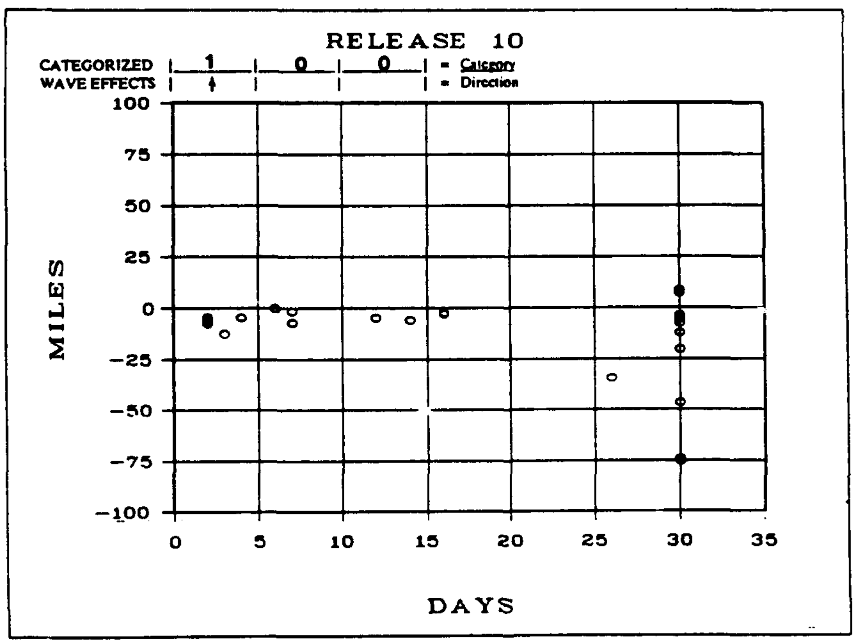
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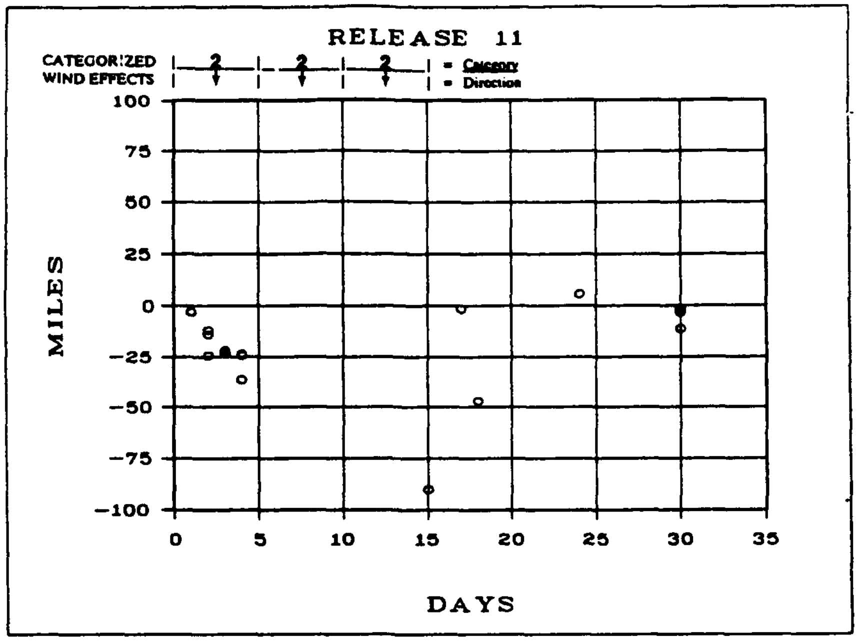
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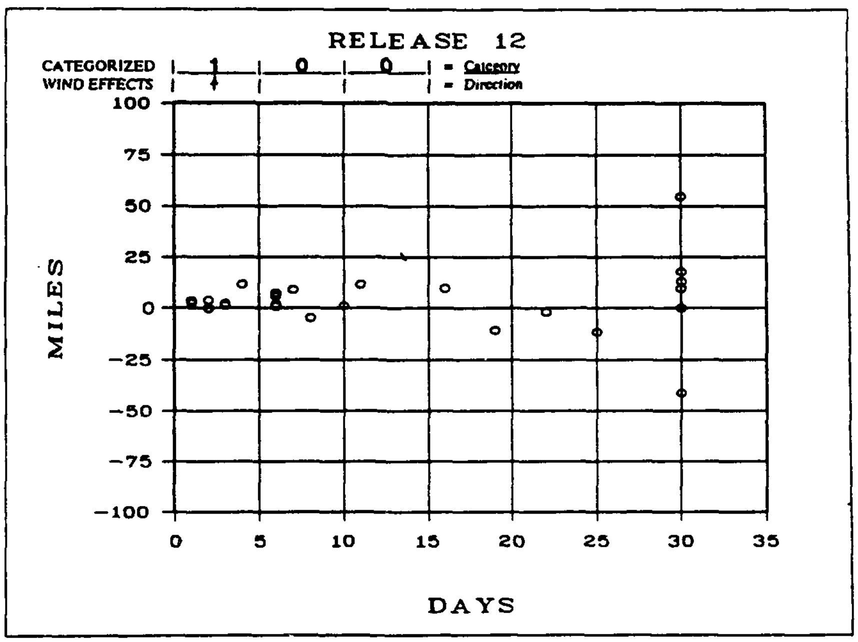
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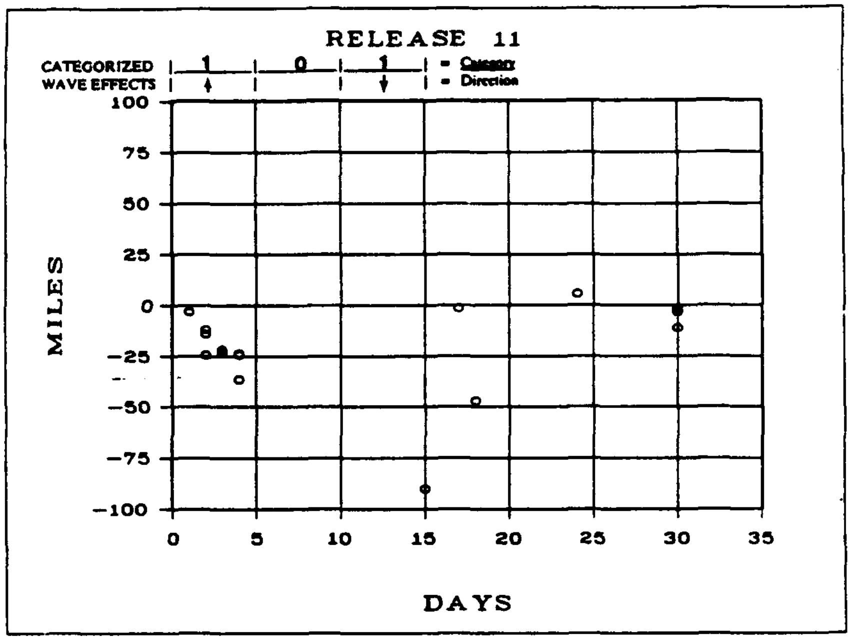
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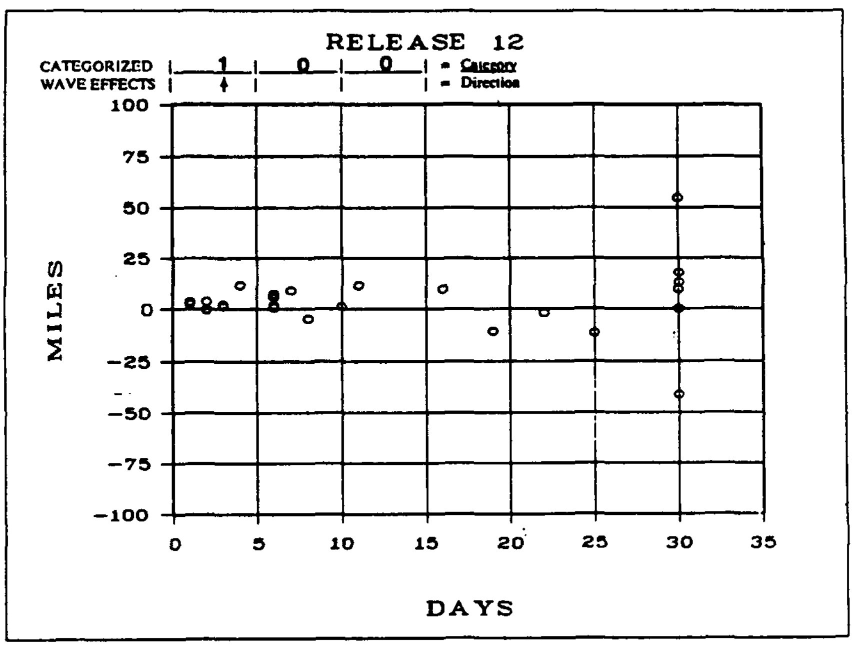
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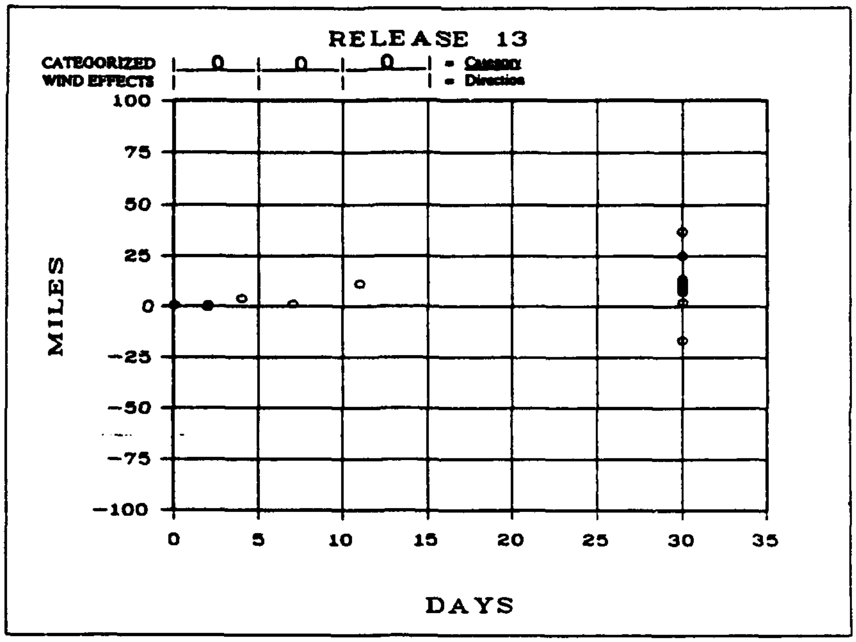
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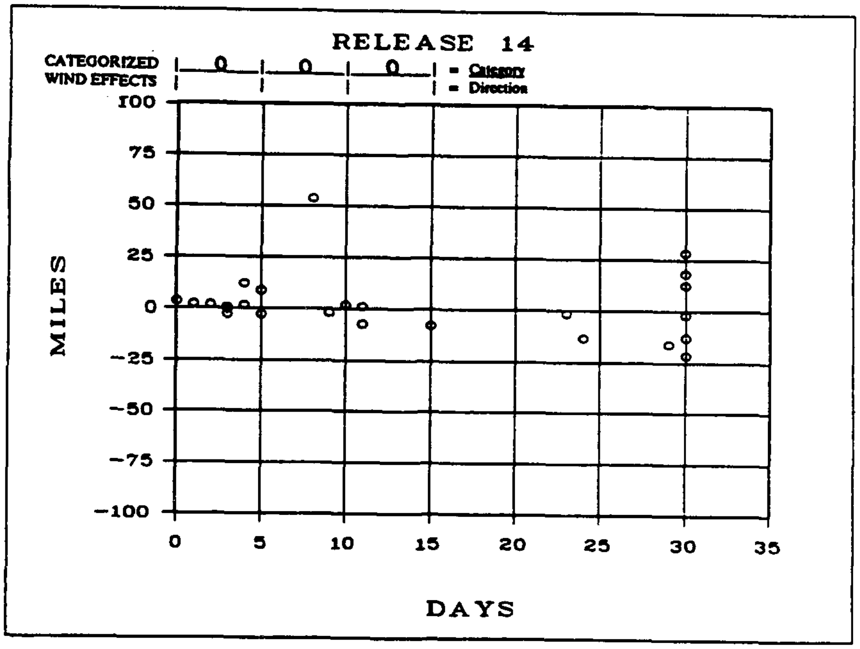
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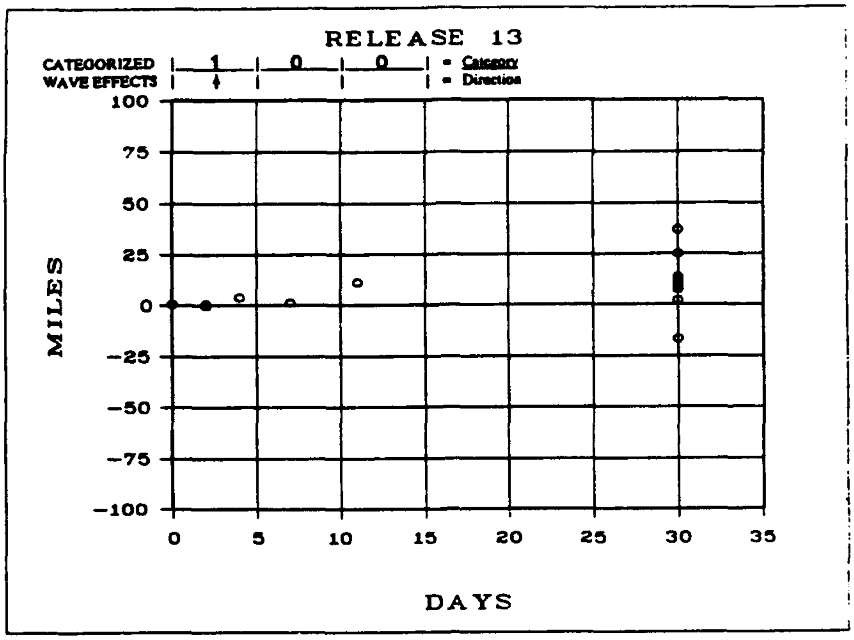
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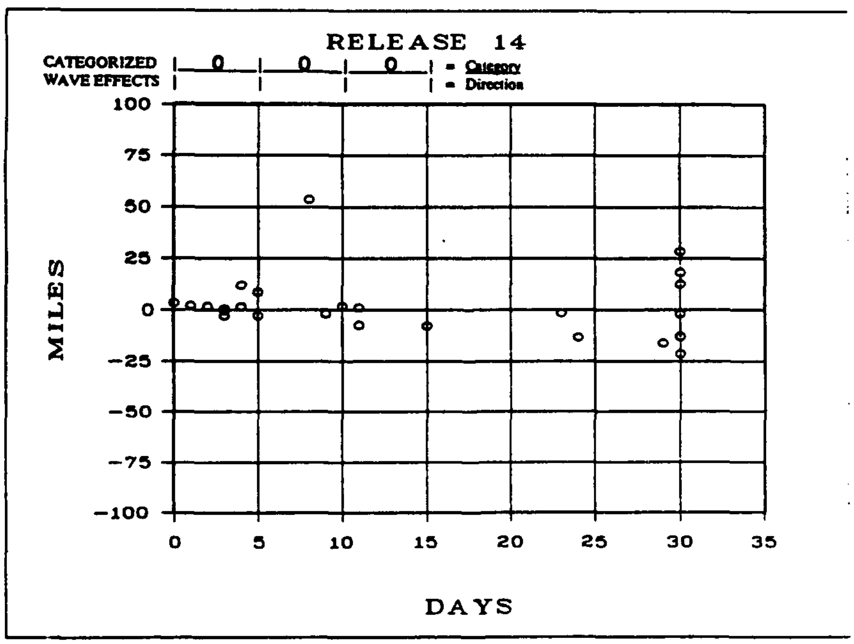
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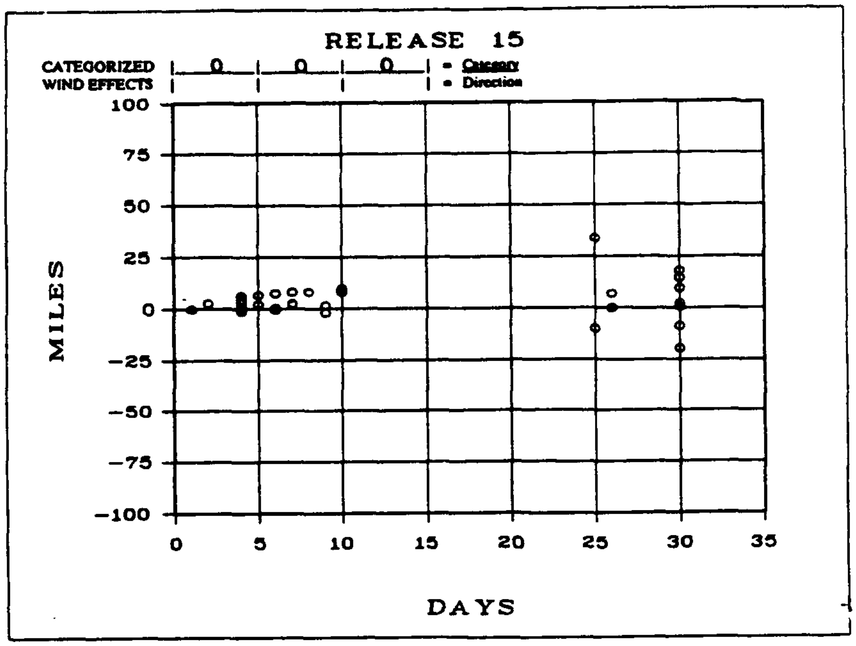
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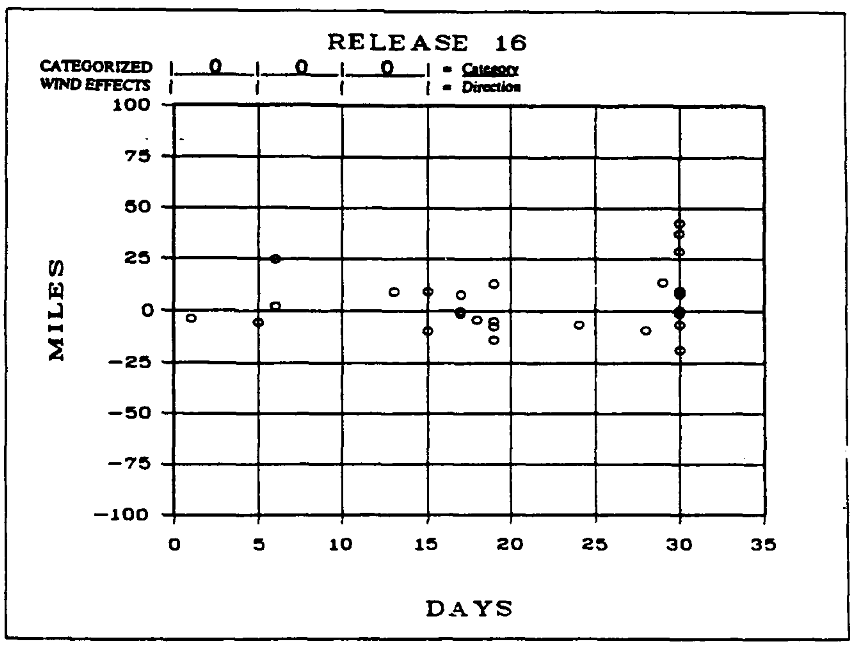
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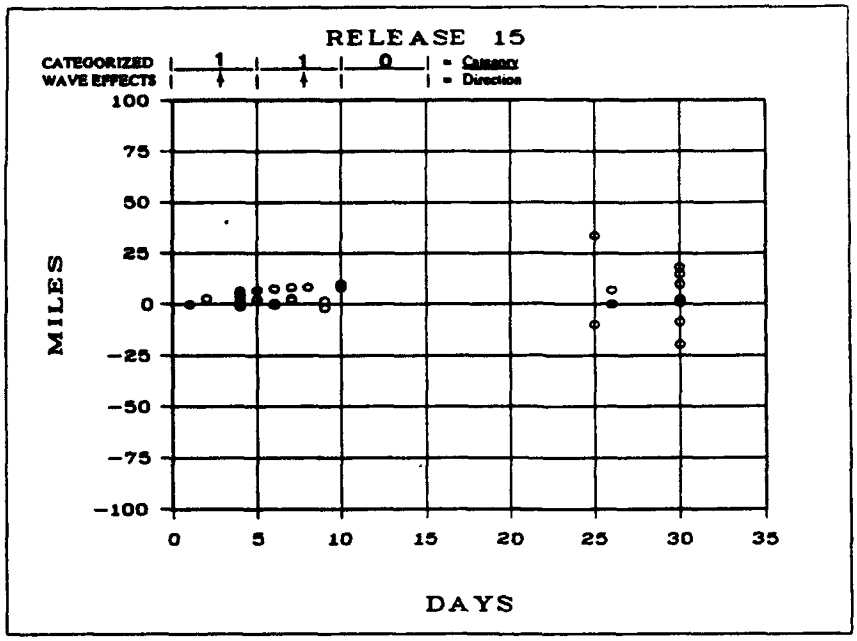
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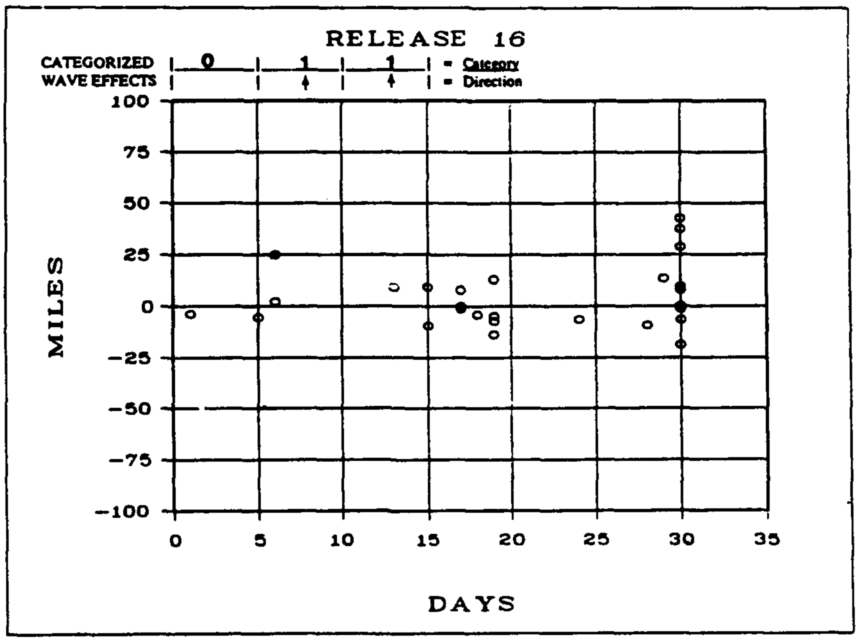
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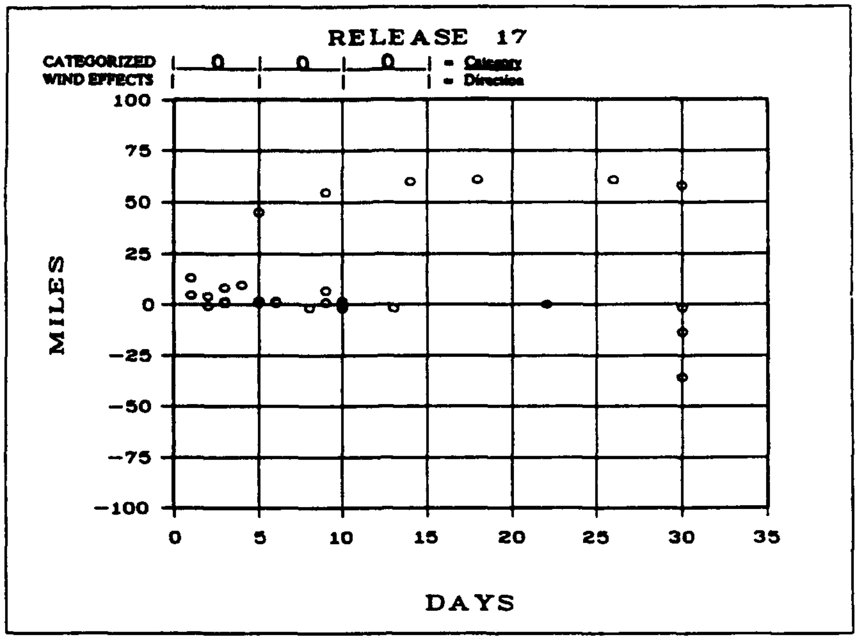
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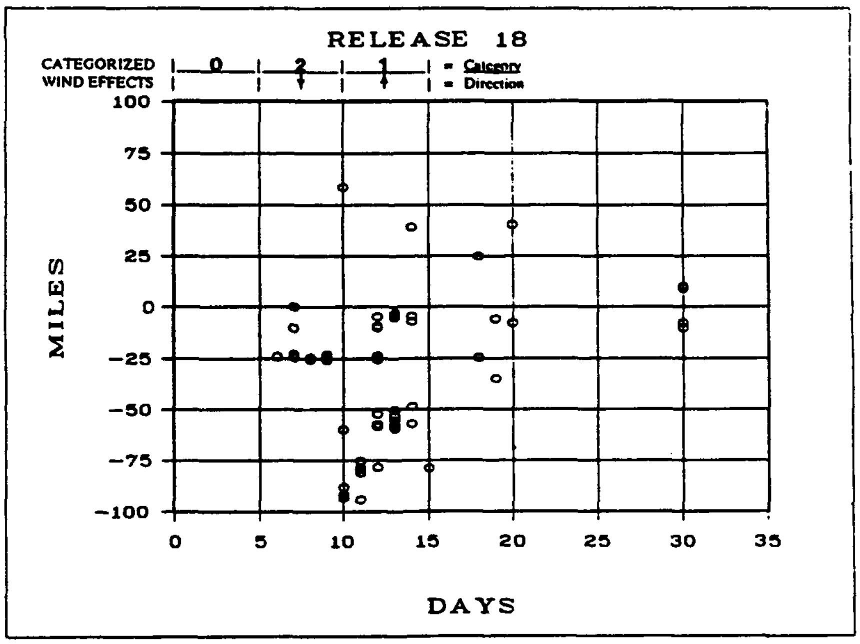
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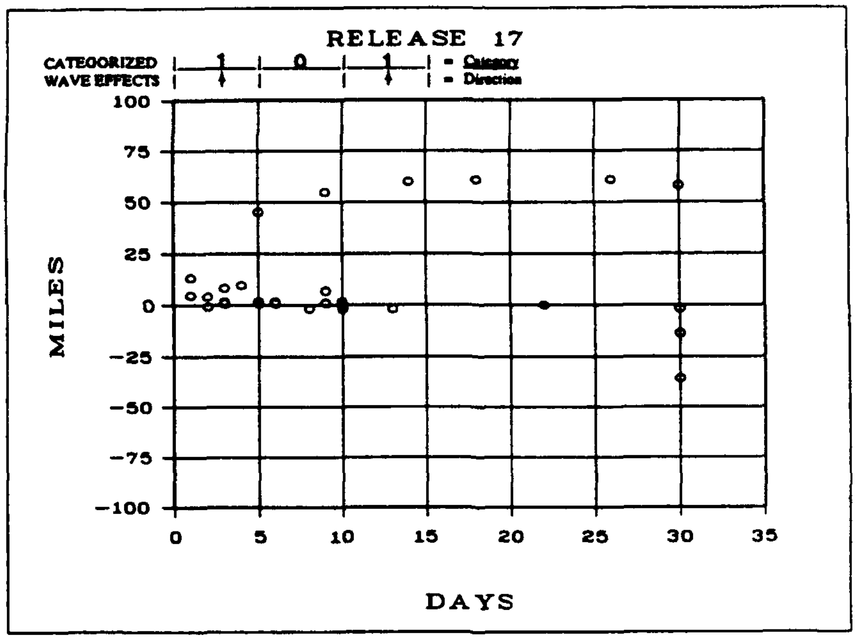
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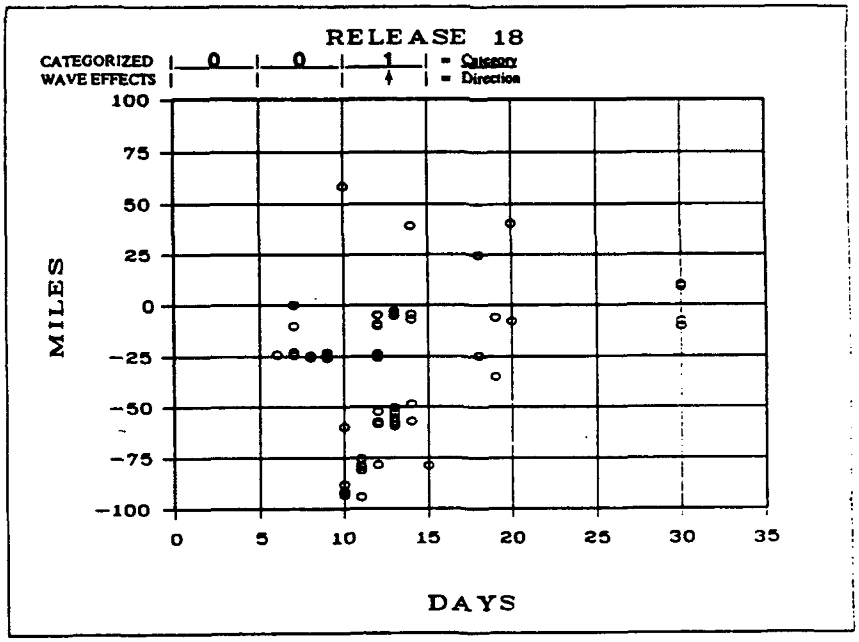
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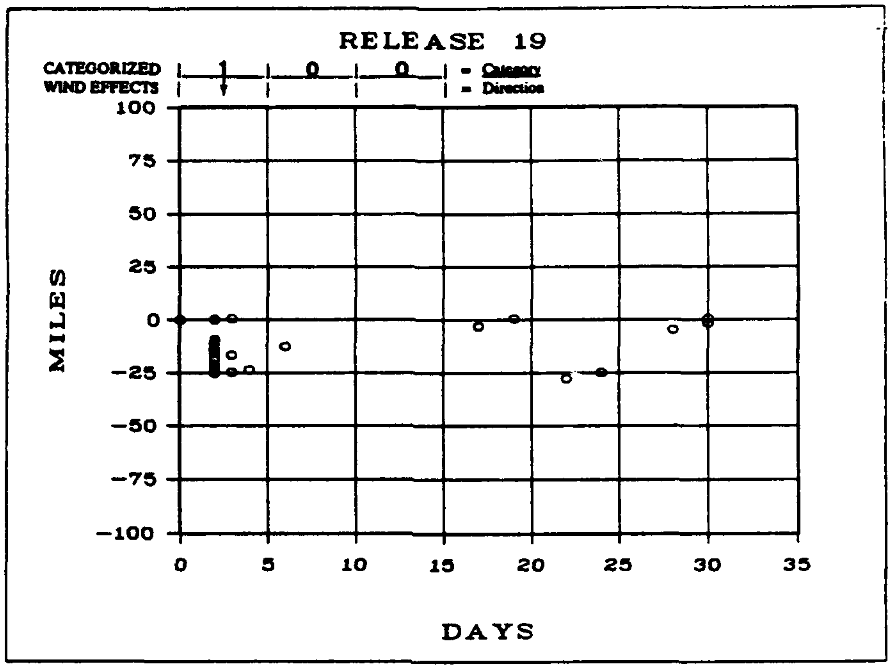
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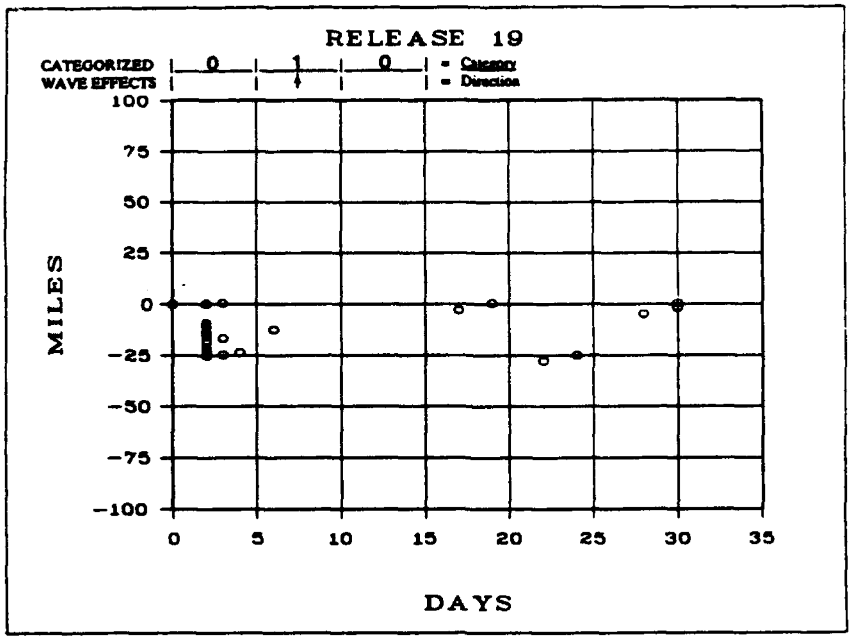
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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
January 1994

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Understanding and Interpreting Seabed Drifter (SBD) Data

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report DRP-94-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Department of the Army
U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Seabed drifters (SBD's) are inexpensive, current-following drogues widely used in oceanographic studies. This report gives new methods for interpreting SBD results, especially for coastal applications. The general forces responsible for SBD movement are described and contrasted with those responsible for moving sediment on the sea floor. Specific recommendations include that a prerelease desk study be done to rank the transport processes at the site of any contemplated SBD application. This ranking will help indicate how useful SBD's may be and provide the basis for selecting an experimental design appropriate for the site. A typical SBD design might include repeated releases of batches of SBD's from a number of stations during varying conditions. Recovery patterns will indicate the relative importance of spatial and temporal variations in the currents. Proper SBD interpretations include assessment of potential human and natural influences on the recovery patterns. Natural dispersion can be divided into a mean (or deterministic) component and a diffusive (or random) component. A methodology is given for quantifying these components. It is shown that the mean displacement of materials suspended in bottom water can exceed 100 km in a few days during a frontal passage or storm. It is important to understand large variations in the mean and random components of displacement to improve predictions of the likely fate of bottom materials. Better predictions can help maximize beneficial uses for dredged materials and minimize adverse effects from accidental ocean discharges that may be unrelated to dredging.

(Continued)

14. SUBJECT TERMS

Bottom currents	Drogues	Onshore transport
Coastal Alabama	Fate of dredged materials	SBD (seabed drifter)
Dispersion	Longshore currents	Tracer

15. NUMBER OF PAGES
152

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

Procedures and analysis techniques proposed here are illustrated using SBD data obtained in Corps studies of areas off the Alabama and North Carolina coasts. Recommendations include continued improvement of interpretation and experiment design guidance, adding SBD's to all appropriate coastal monitoring efforts, and evaluating modifications to the SBD's that could make them respond more like sediment.